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Part 7: Arduino Nano

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AUGUST 2016 £4.40





Development Tool of the Month!

PICkit™ 3 In-Circuit Debugger



Part Number
PG164130

Overview:

Microchip's PICkit™ 3 In-Circuit Debugger/Programmer uses in-circuit debugging logic incorporated into each chip with Flash memory to provide a low-cost hardware debugger and programmer, allowing debugging and programming of PIC® MCU and dsPIC® DSC microcontrollers using the powerful graphical user interface of the MPLAB® X Integrated Development Environment (IDE). The PICkit 3 is connected to the design engineer's PC using a full speed USB interface and can be connected to the target via a Microchip debug (RJ-11) connector.

Key Features:

- ▶ USB (Full speed 12 Mbits/s interface to host PC)
- ▶ Real-time execution
- ▶ Built-in over-voltage/short circuit monitor
- ▶ Supports low voltage to 2.0 volts (2.0v to 6.0v range)
- ▶ Diagnostic LEDs (power, busy, error)
- ▶ Read/write program and data memory of microcontroller
- ▶ Erase of program memory space with verification
- ▶ Freeze-peripherals at breakpoint

Order Your PICkit™ 3 In-Circuit Debugger Today at:
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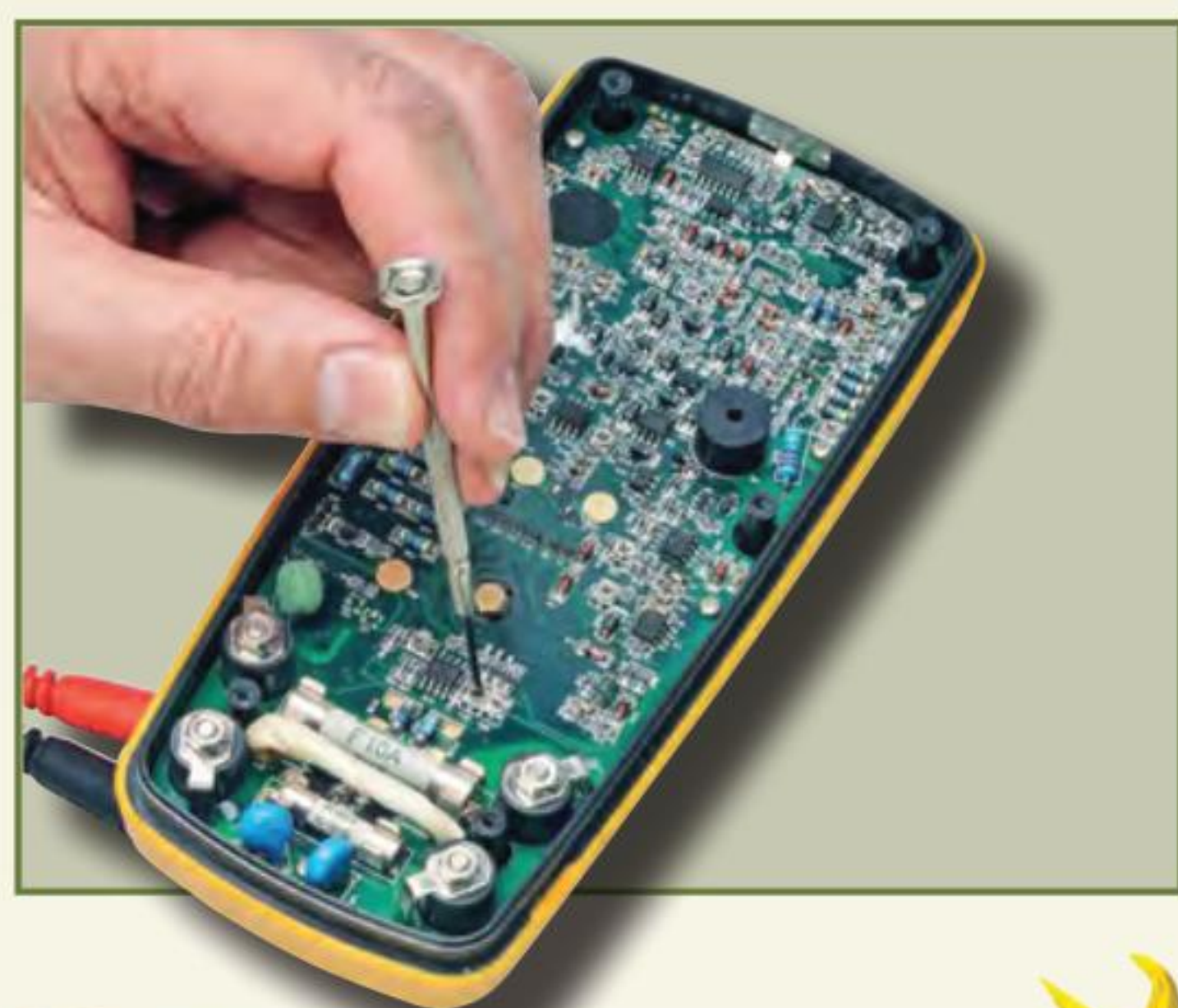
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Our September 2016 issue will be published on Thursday 4 August 2016, see page 72 for details.

Everyday Practical Electronics, August 2016

Projects and Circuits

- LOW-COST, ACCURATE VOLTAGE/CURRENT/RESISTANCE REFERENCE** 12
by Nicholas Vinen
Inexpensive and easy-to-build circuit to help you calibrate meters and circuits
- CHECKING AND CALIBRATING MULTIMETERS** 17
by Nicholas Vinen
How to use our *Reference* to check your multimeter and if necessary, precisely calibrate it on DC voltage, current and resistance
- DRIVEWAY MONITOR – PART 2** 20
by John Clarke
How to build, test and install your *Driveway Monitor*
- USB POWER MONITOR** 30
by Nicholas Vinen
This elegant and compact design enables you to measure the power consumption of USB devices and peripherals

Series and Features

- TECHNO TALK** by Mark Nelson 11
Radio astrology is not nonsense
- TEACH-IN 2016 – EXPLORING THE ARDUINO** 38
by Mike and Richard Tooley
Part 7: Arduino Nano
- PIC n' MIX** by Mike O'Keeffe 45
PICs and the PICkit 3: A beginner's guide – Part 3
- NET WORK** by Alan Winstanley 48
Birthday greetings... Cold War baby... Instant messages... In the Ether
Mail on the move... The rise of ISPs... *EPE* steps online... Spinning a web
- INTERFACE** by Robert Penfold 51
Capacitance Meter Mk2
- CIRCUIT SURGERY** by Ian Bell 54
Ammeters and voltmeters
- AUDIO OUT** by Jake Rothman 60
Super-simple retro amp-speaker combo – Part 2
- MAX'S COOL BEANS** by Max The Magnificent 68
Profligate with power... Is that the time?... Not quite so straightforward

Regulars and Services

- SUBSCRIBE TO EPE** and save money 4
- EPE SUMMER SALE** 5
- EDITORIAL** 7
Happy Birthday *Net Work*!
- NEWS** – Barry Fox highlights technology's leading edge 8
Plus everyday news from the world of electronics
- MICROCHIP READER OFFER** 29
EPE Exclusive – Win one of 10 Microchip MPLAB Xpress Evaluation Boards
- DIRECT BOOK SERVICE** 58
A wide range of technical books available by mail order, plus more CD-ROMs
- EPE CD ROMS FOR ELECTRONICS** 64
A wide range of CD-ROMs for hobbyists, students and engineers
- EPE BACK ISSUES CD-ROM** 66
- EPE PCB SERVICE** 70
PCBs for *EPE* projects
- ADVERTISERS INDEX** 71
- NEXT MONTH!** – Highlights of next month's *EPE* 72

Readers' Services • Editorial and Advertisement Departments

7

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& Enquiries**

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We have a wide range of low cost PIC and ATMEL Programmers. Complete range and documentation available from our web site.

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Leads: Parallel (LDC136) £2.56 | Serial (LDC441) £2.75 | USB (LDC644) £2.14

USB & Serial Port PIC Programmer

USB or Serial connection.
Header cable for ICSP.
Free Windows software.
See website for PICs supported. ZIF Socket & USB lead extra. 16-18Vdc.



Kit Order Code: 3149EKT - ~~£49.96~~ **£23.95**
Assembled Order Code: AS3149E - ~~£38.95~~
Assembled with ZIF socket Order Code: AS3149EZIF - ~~£74.96~~ **£48.95**

USB PIC Programmer and Tutor Board

This tutorial project board is all you need to take your first steps into Microchip PIC programming using a PIC16F882 (included). Later you can use it for more advanced programming. It programs all the devices a Microchip PICKIT2[®] can! You can use the free Microchip tools for the PICKIT2[™] and the MPLAB[®] IDE environment.
Order Code: EDU10 - **£46.74**



ATMEL 89xxxx Programmer

Uses serial port and any standard terminal comms program. 4 LED's display the status. ZIF sockets not included. 16Vdc.



Kit Order Code: 3123KT - ~~£32.95~~ **£21.95**
Assembled ZIF: AS3123ZIF - ~~£48.96~~ **£37.96**

Introduction to PIC Programming

Go from complete beginner to burning a PIC and writing code in no time! Includes 49 page step-by-step PDF Tutorial Manual + Programming Hardware (with LED test section) + Windows Software (Program, Read, Verify & Erase) + a rewritable PIC16F84A. 4 detailed examples provided for you to learn from. PC parallel port. 12Vdc.
Kit Order Code: 3081KT - **£17.95**
Assembled Order Code: AS3081 - **£24.95**



PICKIT[™]2 USB PIC Programmer Module

Versatile, low cost, PICKIT[™]2 Development Programmer. Programs all the devices a Microchip PICKIT2 programmer can. Onboard sockets & ICSP header.
Assembled Order Code: VM203 - **£39.54**



PIC Programmer & Experimenter Board

PIC Programmer & Experimenter Board with test buttons and LED indicators to carry out educational experiments such as the supplied programming examples. Includes a 16F627 Flash Microcontroller that can be reprogrammed up to 1000 times. Software to compile and program your source code is included. Supply: 12-15Vdc.



Kit Order Code: K8048 - ~~£29.58~~ **£21.54**
Assembled Order Code: VM111 - **£38.88**

Controllers & Loggers

Here are just a few of the controller and data acquisition and control units we have. See website for full details. 12Vdc PSU for all units: Order Code 660.446UK £10.68

USB Experiment Interface Board

Updated Version! 5 digital inputs, 8 digital outputs plus two analogue inputs and two analogue outputs. 8 bit resolution. DLL.



Kit Order Code: K8055N - ~~£39.95~~ **£22.74**
Assembled Order Code: VM110N - **£39.95**

2-Channel High Current UHF RC Set

State-of-the-art high security. Momentary or latching relay outputs rated to switch up to 240Vac @ 10 Amps. Range up to 40m. 15 Tx's can be learnt by one Rx (kit includes one Tx but more available separately). Supply 9-15Vdc.



Kit Order Code: 8157KT - **£44.95**
Assembled Order Code: AS8157 - **£49.96**

Computer Temperature Data Logger

Serial port 4-channel temperature logger. °C or °F. Continuously logs up to 4 separate sensors located 200m+ from board. Wide range of free software applications for storing/using data. PCB just 45x45mm. Powered by PC. Includes one DS1820 sensor.
Kit Order Code: 3145KT - ~~£19.95~~ **£16.97**
Assembled Order Code: AS3145 - **£22.97**
Additional DS1820 Sensors - **£4.96 each**



8-Channel Ethernet Relay Card Module

Connect to your router with standard network cable. Operate the 8 relays or check the status of input from anywhere in world. Use almost any internet browser, even mobile devices. Email status reports, programmable timers, ...
Assembled Order Code: VM201 - **£134.40**



4-Ch DTMF Telephone Relay Switcher

Call your phone number using a DTMF phone from anywhere in the world and remotely turn on/off any of the 4 relays as desired. User settable Security Password, Anti-Tamper, Rings to Answer, Auto Hang-up and Lockout. Includes plastic case. 130 x 110 x 30mm. Power: 12Vdc.



Kit Order Code: 3140KT - **£79.95**
Assembled Order Code: AS3140 - **£94.95**

8-Ch Serial Port Isolated I/O Relay Module

Computer controlled 8 channel relay board. 5A mains rated relay outputs and 4 opto-isolated digital inputs (for monitoring switch states, etc). Useful in a variety of control and sensing applications. Programmed via serial port (use our new Windows interface, terminal emulator or batch files). Serial cable can be up to 35m long. Includes plastic case 130x100x30mm. Power: 12Vdc/500mA.



Kit Order Code: 3108KT - **£74.95**
Assembled Order Code: AS3108 - **£89.95**

Infrared RC 12-Channel Relay Board

Control 12 onboard relays with included infrared remote control unit. Toggle or momentary. 15m+ range. 112 x 122mm. Supply: 12Vdc/0.5A



Kit Order Code: 3142KT - ~~£64.96~~ **£51.96**
Assembled Order Code: AS3142 - **£61.96**

Audio DTMF Decoder and Display

Detect DTMF tones from telephone handsets, tape recorders, receivers, two-way radios, etc using the built-in mic or direct from the phone line. Characters are displayed on a 16 character display as they are received and up to 32 numbers can be displayed by scrolling the display. All data written to the LCD is also sent to a serial output for connection to a computer. Supply: 9-12V DC. Main PCB: 55x95mm.
Kit Order Code: 3153KT - **£37.96**
Assembled Order Code: AS3153 - **£49.96**



3x5Amp RGB LED Controller with RS232

3 independent high power channels. Preprogrammed or user-editable light sequences. Standalone option and 2-wire serial interface for microcontroller or PC communication with simple command set. Suitable for common anode RGB LED strips, LEDs and incandescent bulbs. 56 x 39 x 20mm. 12A total max. Supply: 12Vdc.
Kit Order Code: 8191KT - ~~£29.95~~ **£24.95**
Assembled Order Code: AS8191 - **£29.95**



Many items are available in kit form (KT suffix)
or pre-assembled and ready for use (AS prefix)

Hot New Products!

Here are a few of the most recent products added to our range. See website or join our email Newsletter for all the latest news.

4-Channel Serial Port Temperature Monitor & Controller Relay Board

4 channel computer serial port temperature monitor and relay controller. Four inputs for Dallas DS18S20 or DS18B20 digital thermometer sensors (£3.95 each). Four 5A rated relay outputs are independent of sensor channels allowing flexibility to setup the linkage in any way you choose. Simple text string commands for reading temperature and relay control via RS232 using a comms program like Windows HyperTerminal or our free Windows application.
Kit Order Code: 3190KT - £84.95 £59.95
Assembled Order Code: AS3190 - £74.95



40 Second Message Recorder

Feature packed non-volatile 40 second multi-message sound recorder module using a high quality Winbond sound recorder IC. Standalone operation using just six onboard buttons or use onboard SPI interface. Record using built-in microphone or external line in. 8-24Vdc powered. Change a resistor for different recording duration/sound quality. Sampling frequency 4-12 kHz. (120 second version also available)
Kit Order Code: 3188KT - £29.95 £23.96
Assembled Order Code: AS3188 - £31.97



Bipolar Stepper Motor Chopper Driver

Get better performance from your stepper motors with this dual full bridge motor driver based on SGS Thompson chips L297 & L298. Motor current for each phase set using on-board potentiometer. Rated to handle motor winding currents up to 2 Amps per phase. Operates on 9-36Vdc supply voltage. Provides all basic motor controls including full or half stepping of bipolar steppers and direction control. Allows multiple driver synchronisation. Perfect for desktop CNC applications.
Kit Order Code: 3187KT - £39.95
Assembled Order Code: AS3187 - £49.96



LCD Oscilloscope Kit

Build your own oscilloscope with LCD display. Learn how to read signals with this exciting new kit. See the electronic signals you learn about displayed on your own LCD oscilloscope. Despite the low cost, this oscilloscope has many features found on expensive units, like signal markers, frequency, dB, true RMS readouts and more...
Kit Order Code: EDU08 - £49.99



Motor Speed Controllers

Here are just a few of our controller and driver modules for AC, DC, Unipolar/Bipolar stepper motors and servo motors. See website for full details.

DC Motor Speed Controller (100V/7.5A)

Control the speed of almost any common DC motor rated up to 100V/7.5A. Pulse width modulation output for maximum motor torque at all speeds. Supply: 5-15Vdc. Box supplied. Dimensions (mm): 60Wx100Lx60H.
Kit Order Code: 3067KT - £19.95
Assembled Order Code: AS3067 - £27.95



Bidirectional DC Motor Speed Controller

Control the speed of most common DC motors (rated up to 32Vdc/10A) in both the forward and reverse direction. The range of control is from fully OFF to fully ON in both directions. The direction and speed are controlled using a single potentiometer. Screw terminal block for connections.
Kit Order Code: 3166v2KT - £23.95
Assembled Order Code: AS3166v2 - £33.95



Computer Controlled / Standalone Unipolar Stepper Motor Driver

Drives any 5-35Vdc 5, 6 or 8-lead unipolar stepper motor rated up to 6 Amps. Provides speed and direction control. Operates in stand-alone or PC-controlled mode for CNC use. Connect up to six 3179 driver boards to a single parallel port. Board supply: 9Vdc. PCB: 80x50mm.
Kit Order Code: 3179KT - £17.95
Assembled Order Code: AS3179 - £24.95



Computer Controlled Bi-Polar Stepper Motor Driver

Drive any 5-50Vdc, 5 Amp bi-polar stepper motor using externally supplied 5V levels for STEP and DIRECTION control. Opto-isolated inputs make it ideal for CNC applications using a PC running suitable software. Board supply: 8-30Vdc. PCB: 75x85mm.
Kit Order Code: 3158KT - £24.95 £21.20
Assembled Order Code: AS3158 - £31.20



AC Motor Speed Controller (600W)

Reliable and simple to install project that allows you to adjust the speed of an electric drill or 230V AC single phase induction motor rated up to 600 Watts. Simply turn the potentiometer to adjust the motors RPM. PCB: 48x65mm. Not suitable for use with brushless AC motors.
Kit Order Code: 1074KT - £15.95 £13.56
Assembled Order Code: AS1074 - £21.56



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We stock an extensive range of soldering tools, test equipment, power supplies, inverters & much more. Please visit our website to see the full range.

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Features 2 input channels - high contrast LCD with white backlight - full auto set-up for volt/div and time/div - recorder roll mode, up to 170h per screen - trigger mode: run - normal - once - roll ... - adjustable trigger level and slope and much more.
Order Code: APS230 - £299.95 £239.95



Handheld Personal Scope with USB

Designed by electronics enthusiasts for electronics enthusiasts! Powerful, compact and USB connectivity, this sums up the features of this oscilloscope. 40 MHz sampling rate, 12 MHz analogue bandwidth, 0.1 mV sensitivity, 5mV to 20V/div in 12 steps, 50ns to 1 hour/div time base in 34 steps, ultra fast full auto set up option, adjustable trigger level, X and Y position signal shift, DVM readout and more...
Order Code: HPS50 - £239.96 £199.95



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Arduino Starter Kit

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The kit walks you through the Arduino programming and basic electronics in a hands on way. You will be able to build 15 projects using the components supplied. They allow you to control the physical world through different kinds of sensors and actuators. Once you have mastered this knowledge, you will have the ability and circuits to create something beautiful, and make someone smile with what you invent. So build, hack and share!

The Arduino Starter kit is the ideal partner for anyone following the Teach-In 2016 which started in the February 2016 issue of EPE Everyday Practical Electronics.

This Starter kit is supplied with a Wood base, USB & Interconnect leads, Electric motor, Piezo sounder, Movement and Temperature sensors, Switches, LCD, Breadboard & Servo motor. The kit also includes over 100 electronic components:- Diodes, Transistors, Capacitors, h-Bridge, Resistors, LED's, Switches and Trimmers. Quote: EPEARDSK

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2.4GHz Frequency Counter

0.01Hz to 2.4GHz
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Gate Time: 100ms to 10s
2 Channel Operating mode
Power Supply: 110-220Vac 5W
Quote: EPE24G

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PROJECTS AND CIRCUITS

All reasonable precautions are taken to ensure that
the advice and data given to readers is reliable. We
cannot, however, guarantee it and we cannot accept
legal responsibility for it.

A number of projects and circuits published in
EPE employ voltages that can be lethal. You should
not build, test, modify or renovate any item of mains-
powered equipment unless you fully understand the
safety aspects involved and you use an RCD adaptor.

COMPONENT SUPPLIES

We do not supply electronic components or kits for
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We advise readers to check that all parts are still
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EPE EVERYDAY PRACTICAL ELECTRONICS

Happy Birthday Net Work!

Doesn't time fly when you're having fun? Can it really be 20 years since *Net Work* started? Well, it is, and we have quite a treat for you this month and next. Alan Winstanley is looking back over the history of the Internet and *EPE's* long and fruitful relationship with the online community.

I distinctly remember my first contact with the Web in the very early 1990s – it was in a university library, and to be honest, it was less than impressive. For no particular reason I tried to view a painting from the Prado in Madrid. I think it took at least ten minutes to appear and even then it was a fairly crummy jpeg. Underwhelming was my initial reaction, but I made a mental note to keep an eye on the technology's progress.

Then, around the start of the mid-90s, along with many *EPE* readers I took the plunge and bought my first dial-up 14.4kbit/s modem (I think from US Robotics). If all you have ever known is modern cable speeds then 'slow' doesn't even begin to describe the operation of early Internet technology – but, it did work, and for very basic websites and email with modest attachments the system delivered. I got used to the 'sound of the Internet' (<https://youtu.be/p8XKhCfsTts>) and a later jump to a 56k modem felt like moving from a Ford to a Ferrari!

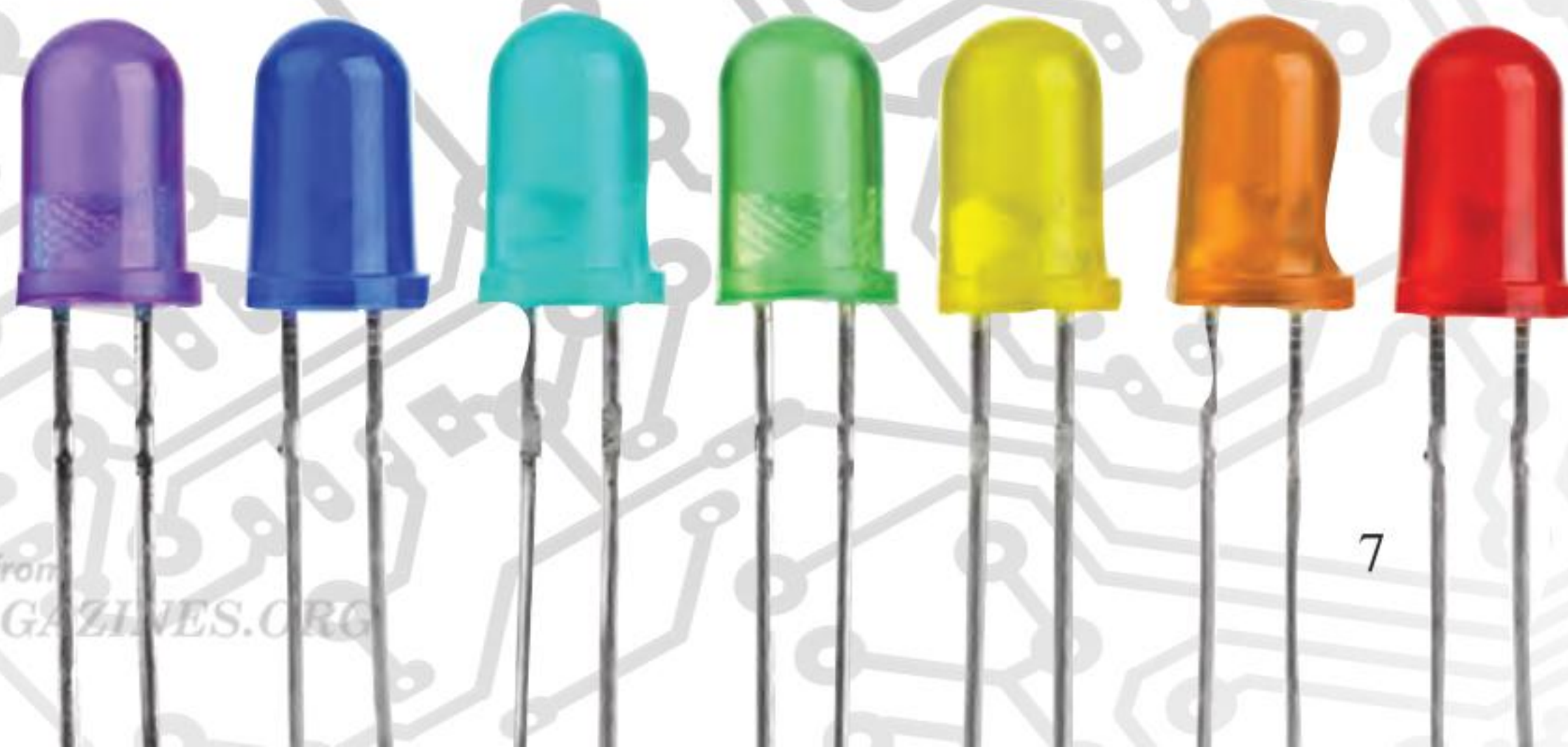
Fast forward 20 years, and like many of you, I cannot imagine working without the Internet. For younger readers, there has never been a time when unlimited digital information, commerce and entertainment were not available 24/7. It has been an amazing revolution, and Alan's trip down memory lane is truly fascinating.

We'd love to hear readers' early online experiences – good, bad, frustrating and funny. Drop us an email at: editorial@wimborne.co.uk

This month

So much for the past, what do we have for you this month – lots of electronic goodies! From *Teach-In 2016* and *Audio Out* to *PIC n' Mix* and *Circuit Surgery* we'll keep you busy and informed for the next four weeks. My top pick this month is the *Low-cost, Accurate Voltage/Current/Resistance Reference* project. It's cheap, quick to build and really everyone should have one. Despite its tiny size it's good enough to calibrate a digital multimeter, but would also be perfectly at home in a larger project; for example, providing a dependable reference voltage for an Arduino's ADC. Build one! You won't regret it.

Mini!



NEWS

A roundup of the latest Everyday News
from the world of
electronics



Why we need a Digital Television Group – report by Barry Fox

The annual Summit conference held in May by the UK's Digital Television Group was short on hot news but neatly proved the need for a DTG – to create order out of the chaos which would surely exist if there were no independent body which the TV industry trusts to set standards, test products to ensure they meet the standards and steer rival TV stations and set-makers into collaboration.

Intermittent muting

In the run-up to this year's event, at the Kings Place concert hall in London's Kings Cross, some TV viewers had been plagued with a mysterious audio fault on all the Freeview high definition channels, but not the standard definition equivalents. On some makes of TV (notably Samsung), but not on others, and not on set-top boxes (eg, Humax), the sound intermittently and apparently randomly mutes.

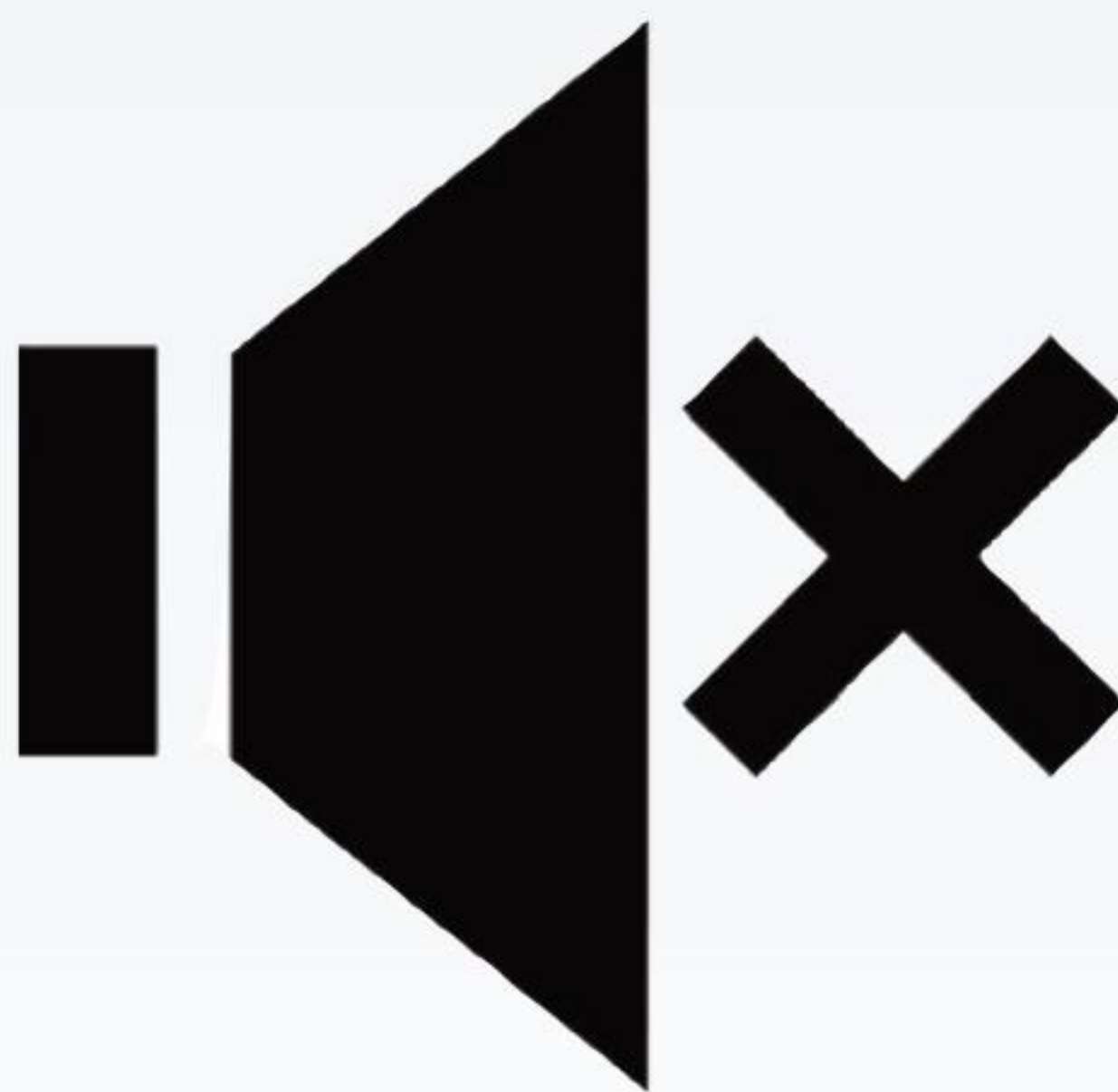
The conference provided an opportunity to talk with the DTG's engineers, who admitted that – like all intermittent, random faults – the HD dropout had been very difficult to isolate and make repeatable. But the DTG thinks it is finally nailed.

CODEC issues

The HE-AAC (High-Efficiency Advanced Audio Coding) audio encoders on the HD multiplex are quite separate from the MPEG (Version 1, Layer 2) encoders used for the SD channels, and earlier this year all the HD encoders were upgraded to tweak their AAC compression with a system called perceptual noise substitution (PNS). This saves bits where wanted audio sounds like unwanted noise. So the coding is continually changing, depending on the sound. Although this was tested

before the upgrade, it later emerged that the decoder chipsets used in some TVs (notably Samsung) cannot cope with some levels of compression, and respond by muting.

The DTG is now co-ordinating a temporary rollback of the encoder upgrade to fix the problem – until the set makers have all developed, tested and pushed out updates to the decoder chipsets locked into viewers' sets. The rollback started in May, just before the DTG conference, and is progressing across the country.



Unwanted audio muting has been plaguing Freeview high definition channels

The DTG is currently holding 'plugfests' to try and pre-empt what could be even more widespread problems if broadcasters press ahead with plans to use HDR (high dynamic range) picture coding. Both Netflix and Amazon have gone ahead with the launch of HDR programming on their 4K Internet services, without waiting for an industry standard, and each uses slightly different systems. Sascha Prueter, Head of Android TV at Google, confirmed that the BBC is now working with YouTube on another system.

LG has adopted the proprietary Dolby Vision system, while Panasonic is

catering for the Netflix and Amazon systems along with HDR10, the Open HDR system used for 4K Blu-ray discs. Disney wants to use HDR, but with conventional 1080p High Definition video, rather than 4K.

The opportunity for chaos is obvious, with HDR video material likely to look worse than non-HDR pictures if displayed on screens that cannot correctly decode the metadata that travels with the picture signal to match the display capability with the source material.

Participants in the DTG's two recent HDR Plugfests, one in Berlin and another in London, told how TV manufacturers at the events were frantically phoning their software labs in India, Korea and Japan to describe problems encountered at the event. Because the events were spread over two days there was no time to get back revised software down a line and try it on the spot.

Subtitle 'triumph'

The DTG's Summit at Kings Place was notable also for proving that live TV subtitling does not have to be as poor as it usually is. The current technique is for a titler to listen to the TV sound through headphones and re-speak the words into a microphone connected to a PC which is running voice recognition software. This overcomes the problem that computer voice recognition cannot (yet) cope with different dialects or accents or mumbling. But inevitably re-speaking creates a significant delay and the software still injects recognition errors, which can only be corrected when the programme is recorded and repeated or replayed later from a Catchup Service such as iPlayer.

The recognition errors are often so gross and hilarious that watching a

Why we need a Digital Television Group *continued*



BBC Breakfast subtitle challenge: do piglets like farmers' wellies?... probably

-muted TV screen in a club, pub or airport waiting zone has become a whole new form of entertainment. The errors are also deeply frustrating for the prime target audience, the deaf and hard of hearing.

At the DTG Summit, some members of the audience gradually realised that the subtitles for the on-stage talk which were continuously displayed live on screens alongside the stage were remarkably accurate and only slightly behind the speech; and this was despite the fact that many of the

speakers were talking very fast, and using TV industry jargon.

How is this happening so extraordinarily well, we asked; how can re-voicing and software recognition be so rapid and accurate? Up on screen, to spontaneous applause from the hall, came a direct reply from the titler: 'I am a stenographer'.

The DTG later explained that it had hired a 'verbatim' court stenographer with a dedicated keyboard that captures words as shorthand keystroke combinations which computer software then outputs as plain text. The DTG says it is now co-operating with the UK's telecoms regulator Ofcom on a report, which asks why TV subtitling is so bad, and whether it has to be so bad. Hopefully, someone from Ofcom was at the DTG Summit to see first hand evidence that it doesn't have to be so bad. But the cost will increase because it takes literally years of training to learn to capture in real time.

Major Bluetooth upgrade

The Bluetooth Special Interest Group (SIG) has announced that its next release of the wireless communications standard (arriving late 2016 to early 2017), will be called Bluetooth 5 and will include significantly increased range, speed, and broadcast messaging capacity.

The claimed objectives are: 'extending range to deliver robust, reliable Internet of Things (IoT) connections that make full-home and building and outdoor use a reality. Higher speeds will send data faster and optimise responsiveness. Increasing broadcast capacity will propel the next generation of "connectionless" services like beacons and location-relevant information and navigation. These Bluetooth advancements open up more possibilities and enable SIG companies to build an accessible, interoperable IoT.'

From app to IoT

Bluetooth 5 will quadruple range and double the speed of low energy connections while increasing the capacity of connectionless data broadcasts by 800 per cent. With the major boost in broadcast messaging capacity, the data being transferred will 'be richer and, more intelligent'. A key aim is to redefine the way Bluetooth devices transmit information, moving away from the app-paired-to-device model

to a connectionless IoT where there is less need to download an app or connect the app to a device.

More than 371 million Bluetooth-enabled beacons are projected to ship by 2020, according to Patrick Connolly, Principal Analyst at ABI Research. With eight times the broadcast messaging capacity, Bluetooth 5 will further propel the adoption and deployment of beacons and location-based services in the home automation, enterprise, and industrial markets. In scenarios where contextual awareness like navigation and pin-point location are crucial – such as hassle-free airport navigation, asset tracking of warehouse inventory, emergency response and even smart city infrastructure that helps the visually impaired be more mobile – Bluetooth 5 will send custom information people actually find useful in that moment without connection and application barriers.

Mark Powell, executive director of the Bluetooth SIG said, 'Today, there are 8.2 billion Bluetooth products in use, and the enhancements in Bluetooth 5 and planned future Bluetooth technical advancements mean that Bluetooth will be in more than one-third of all installed IoT devices by 2020. The drive and innovation of Bluetooth will ensure our technology continues to be the IoT solution of choice for all developers.'



Hammond miniature USB enclosures



To house small PCBs using USB as the external power and signal interconnect, Hammond Electronics has extended its popular 1551 miniature family with three new sizes: 35, 50 or 65mm long, 20, 25 or 30mm wide respectively, all 15.5mm high. The sizes provide prototype builders and small volume producers generous room for their PCB. All versions feature a dedicated cut-out for a standard USB Type A plug in one end.

Zinc grid-scale batteries

Researchers at Stanford University have designed a battery to help with grid-scale energy storage.

'Solar and wind farms should be able to provide around-the-clock energy for the electric grid, even when there's no sunlight or wind,' said Stanford researcher, professor Cui. "That will require inexpensive batteries and other low-cost technologies big enough to store surplus clean energy for use on demand."

The researchers designed a novel battery with electrodes made of zinc and nickel, inexpensive metals.

A variety of zinc-metal batteries are available commercially, but few are rechargeable, because tiny fibres called dendrites form on the zinc electrode during charging. These dendrites can grow until they finally reach the nickel electrode, causing the battery to short circuit and fail.

The research team solved the dendrite problem by simply redesigning the battery. Instead of having the zinc and nickel electrodes face one another, as in a conventional battery, the researchers separated them with a plastic insulator and wrapped a carbon insulator around the edges of the zinc electrode. Even if zinc dendrites form, they will grow away from the nickel electrode and will not short the battery.

To demonstrate stability, the researchers successfully charged and discharged the battery more than 800 times without shorting.

"Our design is very simple and could be applied to a wide range of metal batteries," Cui said.

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Radio astrology is not nonsense

TechnoTalk

Mark Nelson

No, that's not a misprint, as can be proven in a contrived sort of way. Radio astrology may not be a very practical application of electronics, but this did not stop RCA from taking it seriously. Plus, is making your own microprocessors from transistors a practical business?

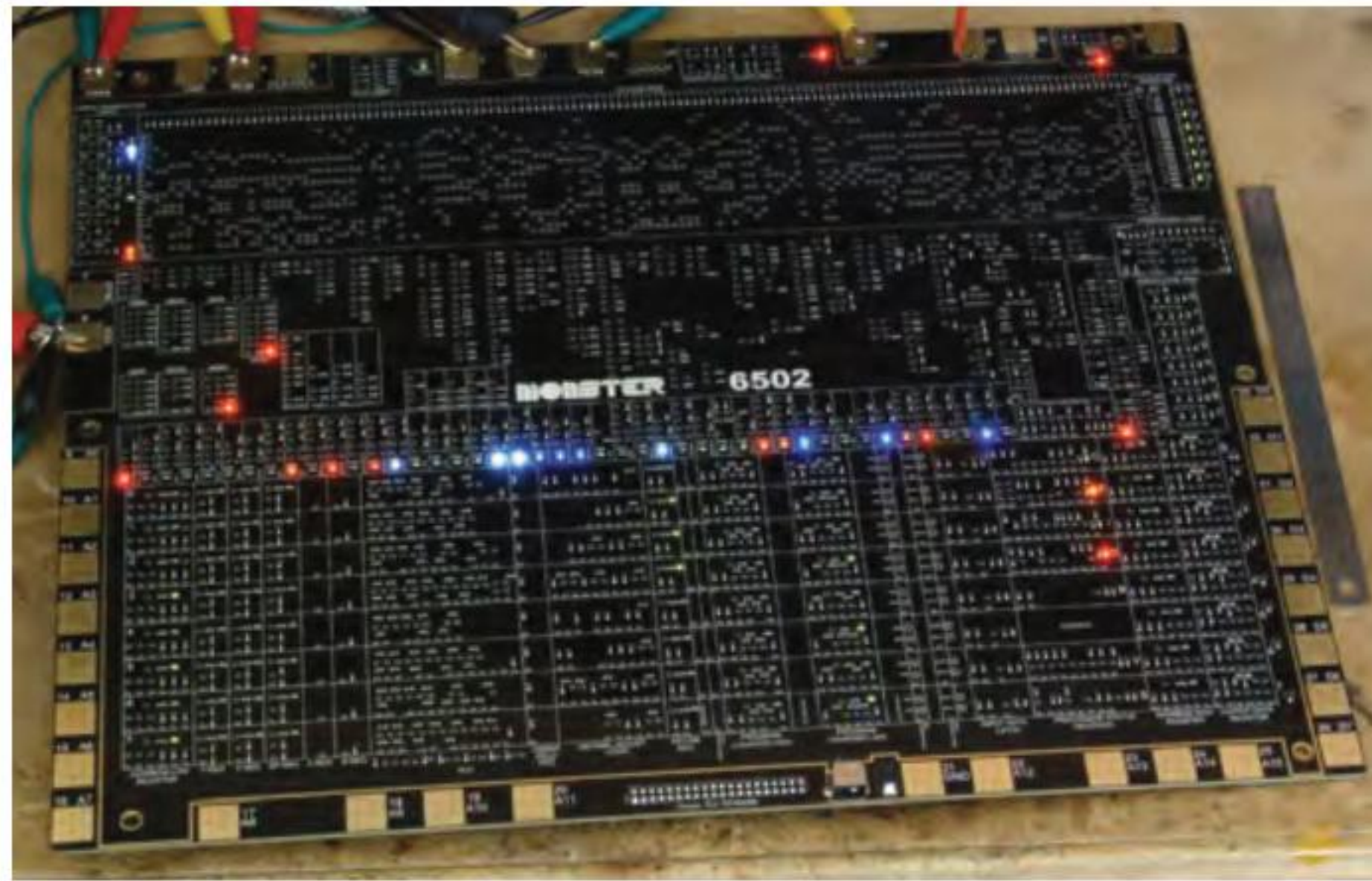
ONLY A COUPLE OF LETTERS differentiate astrology from astronomy, so much so that both subjects used to be jumbled side-by-side on the magazine shelves of my local branch of WH Smith. And why on earth not? Both activities involve scanning the heavens in order to gain better understanding. Even so, you and I probably agree there's a distinction between looking to the skies for predicting the future, or alternatively for puzzling out the cosmos and other worlds.

It was not always so of course. Earlier civilisations, notably the Babylonians, Ancient Greeks, Egyptians and Persians, carried out methodical observations of the night sky and performed mathematical calculations not only for navigational purposes and making calendars, but also to predict all manner of future events. They saw no distinction between these applications and showed no intellectual snobbery towards speculative 'fortune telling'. But 65 years ago the respected *Time* magazine in the US reported: 'This week Radio Corporation of America, no easy prey to superstition, announced in the *RCA Review* that it is successfully predicting radio reception by a study of planetary motions.' So radio astrology was not a joke after all then?

Two kinds of radio astrology

I should clarify that there's radio astrology and radio astronomy. The first kind uses radio astronomy techniques for astrological purposes and the second uses astrological techniques for radio purposes. As far as I know, the first of these has not been put to the test, even though when I was a student at Kent university back in the late 1960s, Prof Jennison did set up a mobile radio astronomy station that we students dubbed a radio astrology research station. But the second application, studying the interaction of the planets to forecast radio propagation, did indeed take place in 1951 when RCA became involved in a project to anticipate magnetic storms that hampered short-wave radio reception from across the Atlantic.

Summarising the many reports on the Internet, RCA Communications Co. in New York was keen to mitigate poor shortwave propagation in the north Atlantic region. One of their engineers, by the name of John H Nelson, developed this by comparing planetary



Building a microprocessor using discrete components is not a trivial pursuit [photo courtesy of Evil Mad Scientist Laboratories]

positions relative to the sun with logs of propagation conditions from RCA's receiving station at Riverhead, Long Island. Astronomy was Nelson's hobby, and RCA built a small observatory for him to do the research. His article in *RCA Review* of March 1951 observes that more storms occurred when two or more planets were in configuration and stated that certain configurations of the six inner planets correlated positively with degraded propagation conditions.

Not dogmatic

Nelson was not dogmatic about his theory, however, and in this and in a follow-up article published in the May 1952 issue, he encouraged further study. Nevertheless, he believed that his theory was about 85 per cent accurate in its predictions, although these were based on a small number of observations. Some observers consider that there is merit in Nelson's theory, although RCA appears not to have taken it further.

David Dalton (callsign K9WQ), who has researched the subject in some detail, says that as far as he can determine from searching the Internet, few or no studies have been done to test Nelson's theory. He concludes: 'If you search the Web for references to John H Nelson as I did, you will find that certain astrologers and UFO enthusiasts took an interest in his theory. I'm not really sure why – perhaps because it was seen as scientific evidence that planetary positions might affect conditions on earth. However, I don't think that we should dismiss Nelson's theory based on its interest to astrologers. Also, I personally would be sceptical of attempts to dismiss Nelson's theory

based only on purely theoretical explanations of why it can't be. Rather, the real work would be in an objective analysis of a well-calculated 'Nelson index' against actual propagation data. I have only scratched the surface and found it intriguing.'

Doing it the hard way

According to Miles Kington, knowledge is being aware that a tomato is a fruit rather than a vegetable,

whereas wisdom is knowing not to put it in a fruit salad. In similar vein, microprocessor chips contain a vast number of individual transistors but you wouldn't try making your own microprocessor from discrete transistors – or would you? Someone who certainly would is Eric Schlaepfer, in collaboration with Evil Mad Scientist Laboratories, whose motto is 'Making the world a better place, one Evil Mad Scientist at a time'.

Eric calls his creation the 'MONster 6502': a transistor-scale replica of the revered MOS 6502 microprocessor that powered some influential early computer systems such as the Apple II and the Commodore PET. His monstrous replica is huge, measuring 12 x 15 inches and containing more than 4,000 surface mount components. Thoughtfully he has added 167 indicator LEDs so that you can see data as it flows through the device. The prototype's first public sighting was at the San Francisco 'Bay Area Maker Faire' in May of this year. Eric emphasizes that the MONster 6502 is not yet a kit or product that you can buy, but this might change. If you would like to stay in the loop as Eric's vast project evolves, he has set up a special mailing list. You can read more about the MONster 6502 on its main project page, monster6502.com (where you can discover whether Eric is nuts, and sign up to be on the mailing list), and at Eric's eclectic blog, tubetime.us. The Evil Mad Scientist website is, predictably, at www.evilmadscientist.com. Maker Faires, with all kinds of weird and wonderful on display, are now held all over the world (see <http://makerfaire.com>).

Low-cost, Accurate Voltage/Current/Resistance Reference

This small module is based on a lithium coin cell, a voltage reference IC, a precision resistor and little else. It provides a reference voltage of $2.5\text{V} \pm 1\text{mV}$ ($\pm 0.04\%$), a resistance of $1\text{k}\Omega \pm 1\Omega$ ($\pm 0.1\%$) and a current of $2.5\text{mA} \pm 3.5\mu\text{A}$ ($\pm 0.14\%$). It can be used for checking or calibrating multimeters or anywhere that an accurate and stable voltage is required.

By Nicholas Vinen



How accurate are your multimeters? This accurate *Voltage/Current/Resistance Reference* is ideal for checking and calibrating multimeters on a regular basis.

THIS SMALL module can be kept with your multimeter or other test instrument and used to periodically check its calibration. With occasional use, the battery will last for its shelf life, which is normally at least 10 years for a fresh cell.

It can sink or source up to 10mA so the accuracy of the reference voltage is not affected by bias currents and a divider can be connected across the outputs to provide lower reference voltages, as long as its impedance is at least 250 Ω . For example, this would allow it to be used in combination with our *Lab-standard 16-Bit Digital Potentiometer* from the July 2012 issue to give an adjustable reference voltage from 0V to 2.5V in 38 μV steps.

It could also be hooked up to a microcontroller to be used as an analogue-to-digital converter (ADC) reference voltage, for accurate voltage measurements by the micro.

This project effectively supersedes the *Precision 10V Reference* published in the May 2015 issue (and the one from June 2011 too). While this one is not adjustable and its output voltage is lower, its basic accuracy is better, it's much smaller and cheaper to build, uses a much smaller (and cheaper) battery and the previous projects did not offer the resistance or current references.

Circuit description

The full circuit is shown in Fig.1 and there isn't much to it. IC1 is the Maxim voltage reference

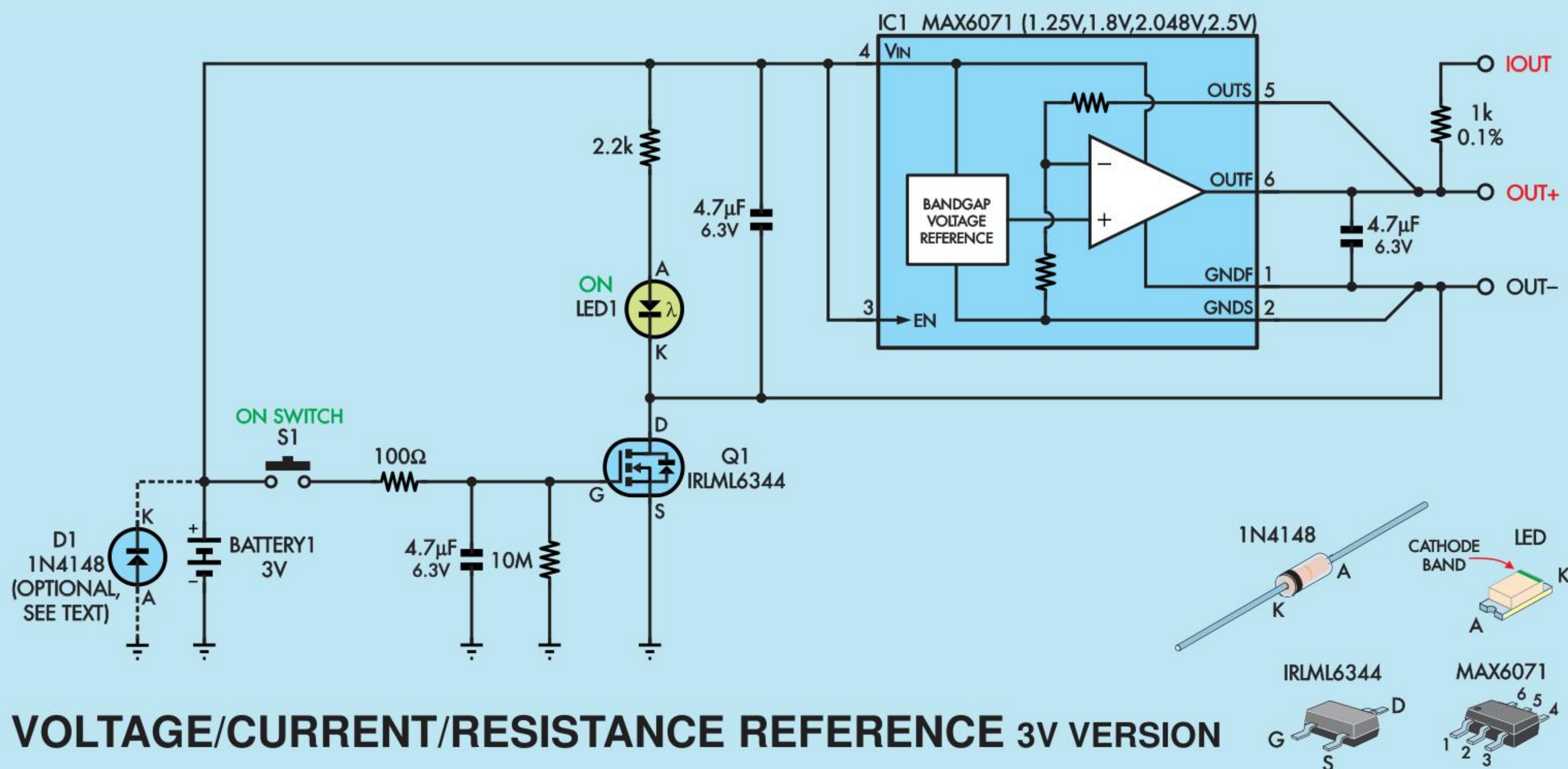


Fig.1: the circuit is based on a MAX-6071 2.5V precision voltage regulator. MOSFET Q1 switches power to the circuit for 15-20s whenever pushbutton switch S1 is pressed.

which contains a band-gap circuit and precision op amp with trimmed resistive divider. The band-gap circuit measures the voltage across a couple of PN junctions and incorporates temperature compensation so that its output is stable (typically just 1.5ppm change per degree Celsius).

The band-gap reference produces 1.25V and the internal op amp and resistors provide a suitable gain to give the specified output. In this case, we're using a 2.5V reference, although other values are available and can be substituted.

We're using 4.7μF input bypassing and output filtering capacitors for a stable output voltage. LED1 and its series current-limiting resistor are connected across the reference's supply so that the LED lights whenever the reference is powered.

MOSFET Q1, together with push-button S1 and the RC network, switches power to the reference for a limited time, so that the cell won't be accidentally discharged.

When S1 is pressed, a third 4.7μF capacitor charges from the 3V battery supply via a 100Ω current-limiting resistor. This capacitor is connected between Q1's gate and source terminals so when it charges up, Q1 switches on

Features and specifications: 2.5V version

Reference voltage: 2.5V ± 1mV, 0-10mA sink/source

Reference current: 2.5mA ± 1.4μA, 1kΩ source impedance

Reference resistance: 1kΩ ± 1Ω, 1/8W

Power supply: 3V lithium button cell

Operating current: ~600μA

Standby current: < 1μA

Cell life: typically > 10 years with intermittent use

Other features: auto-off (20s), power indicator LED, compact size

and connects the reference ground to battery ground, thus switching it on.

A 10MΩ resistor across this 4.7μF capacitor discharges it over the course of about 15-20 seconds and once its voltage drops low enough, Q1 switches off and current flow from the battery ceases. Thus, S1 is pressed before the reference is used and provides power for long enough for a measurement to be taken. Total current draw is around 0.6mA when the reference is powered (150μA for IC1 and 450μA for LED1) and Q1's leakage current when off is less than 1μA.

The output reference voltage is available between the OUT+ and OUT- pads on the PCB. A 0.1% 1kΩ precision resistor is connected between OUT+ and IOUT and so resistance calibration can be performed between these two terminals. Together, the voltage reference and precision resistor provide

an accurate 2.5mA current between the IOUT and OUT- terminals. The separate calibration article in this issue describes how measurement shunt resistance can affect this current.

Note that if all you want is a voltage reference, you can leave the 0.1% resistor out of the circuit.

Some button cell holders (including the type Jaycar stocks) will not apply power to the circuit if the cell is inserted upside-down. However, some do but we can't use a series diode for reverse polarity protection as we normally would, since IC1 requires a minimum of 2.8V to operate and even a Schottky diode would reduce the 3V from the cell by too much.

Thus, an optional 1N4148 diode (D1) can be reverse-connected across the holder to provide protection in case the cell is accidentally inserted backwards. The internal resistance for a

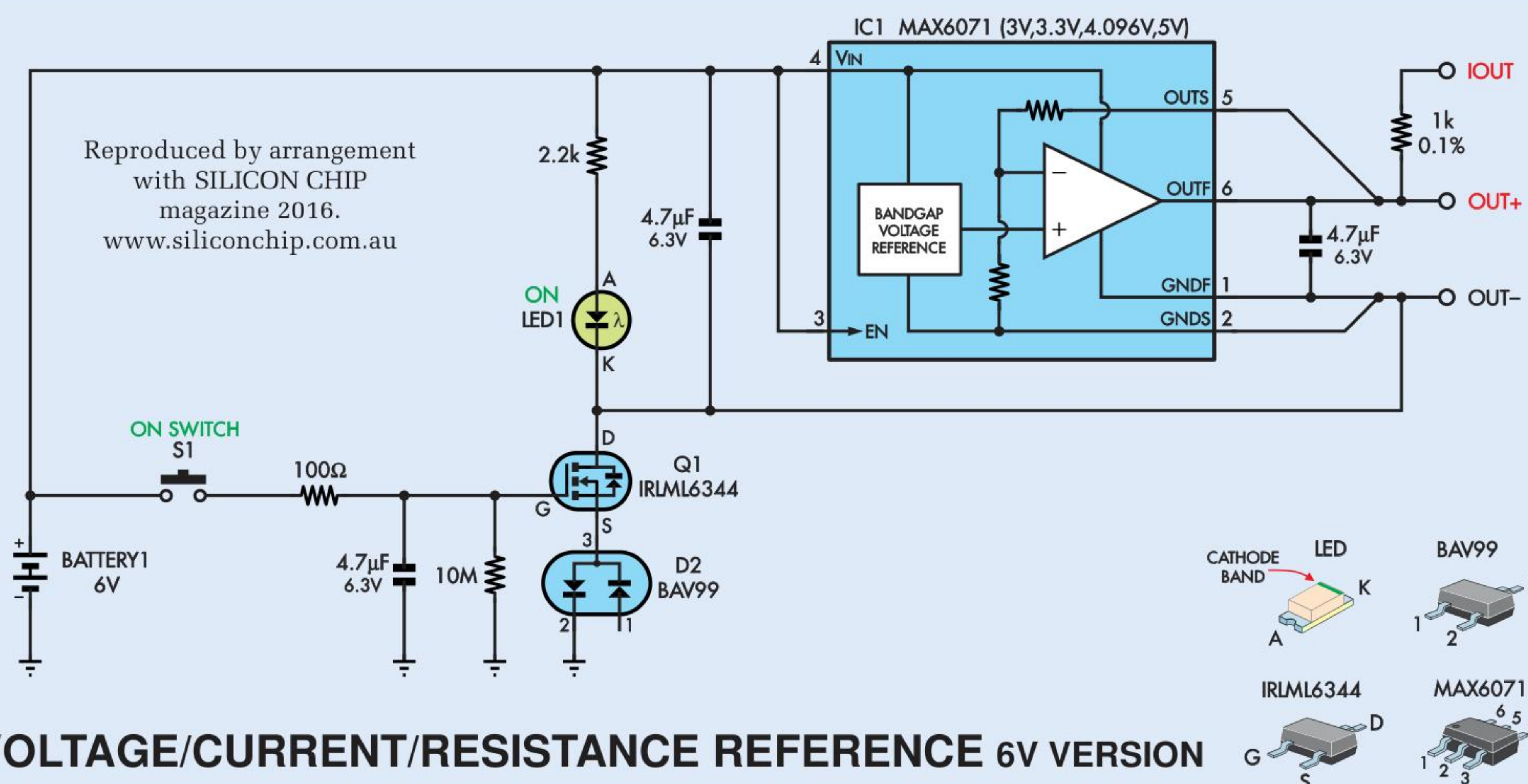


Fig.2: this alternative circuit is used for output voltages of 3V or more. It's powered by a 2-cell (6V) battery and diode D2 is included to reduce the supply voltage to 5.5V.

Parts list

- 1 double-sided PCB, available from the *EPE PCB Service*, coded 04108151, $44.5 \times 23\text{mm}$
- 1 tactile pushbutton with short actuator
- 1 50mm length 20mm-diameter clear heatshrink tubing

Semiconductors

- 1 IRLML6344 N-channel MOSFET,
SOT-23 package (Q1)
1 1N4148 small signal diode (D1)

**Capacitors (SMD 3216 [1206]
or 2012 [0805])**

- 3 4.7 μ F 6.3V X5R/X7R ceramic

**Resistors (1% SMD 3216 [1206]
or 2012 [0805])**

- 1 10M Ω 1 2.2k Ω
1 1k Ω 0.1% 2012/0805
1 100 Ω

Additional parts for versions up to 2.5V output

- 1 20mm button cell holder (Jaycar PH9238, Altronics S5056)
- 1 CR2032 3V lithium cell
- 1 MAX6071AAUT25+T 2.5V reference IC* (IC1)
- 1 high-brightness red, green or yellow LED, SMD 3216 (1206) or 2012 (0805) package (LED1) (eg, element14 2290347)
- 1 1N4148 small signal diode (D1)

- * OR**
- 1 MAX6071AAUT12+T for 1.25V output
 - 1 MAX6071AAUT18+T for 1.8V output
 - 1 MAX6071AAUT21+T for 2.048V output

Additional parts for versions over 2.5V output

- 1 dual 20mm button cell holder
plus 2 × CR2032 3V lithium
cells

OR

- 1 20mm button cell holder
(Jaycar PH9238, Altronics
S5056) plus 2 x CR2016 3V
lithium cells
- 1 MAX6071AAUT50+T 5V output
reference IC** (IC1)
- 1 high-brightness blue LED,
SMD 3216 (1206) or 2012
(0805) package (LED1) (eg,
element14 2217982)
- 1 BAT54S or BAT54C dual
SMD Schottky diode, SOT-23
package (D2)

**** OR**

- 1 MAX6071AAUT30+T for 3V output
1 MAX6071AAUT33+T for 3.3V output
1 MAX6071AAUT41+T for 4.096V output

CR2032 cell is typically 10Ω so if your holder does allow a cell to make contact upside-down, D1 should survive long enough for you to realise your mistake and protect IC1 from damage.

Different output voltages

IC1 can be changed to a 1.25V, 1.8V or 2.048V type with no other changes to the circuit. This is simply a matter of using an IC with a different part number (see the parts list).

We have chosen 2.5V as the ‘default’ option since this is the highest reference voltage obtainable using a single lithium cell. However, 1.8V is also a good choice as many low-cost DMMs have a 2V range and thus this will be ideal for calibrating them. The 2.5V option works well for meters with a 4V range, which is quite common for more expensive multimeters.

You can also get an output of 3V, 3.3V, 4.096V or 5V, but this will require a 2-cell battery to provide a sufficiently high input supply voltage. You have two options: either use a standard button cell holder and two slim cells (CR2016, ~100mAh) or use a double-stack cell holder and two of the more common CR2032 cells (~200mAh).

There are two advantages to using

CR2016: (1) you can get the holder and cells from a local store, and (2) the resulting unit is a little more compact. Unless you will be using the unit frequently, the reduced cell capacity probably won't matter.

Regardless, when using two cells, diode D2 will need to be fitted. That's because IC1's maximum recommended operating voltage is 5.5V and D2's forward voltage will reduce the ~6V from two fresh cells to be very close to 5.5V. The alternative circuit is shown in Fig.2. With D2 in circuit, there's no need to fit D1 as D2 will block reverse current. Otherwise, the circuit remains the same.

Construction

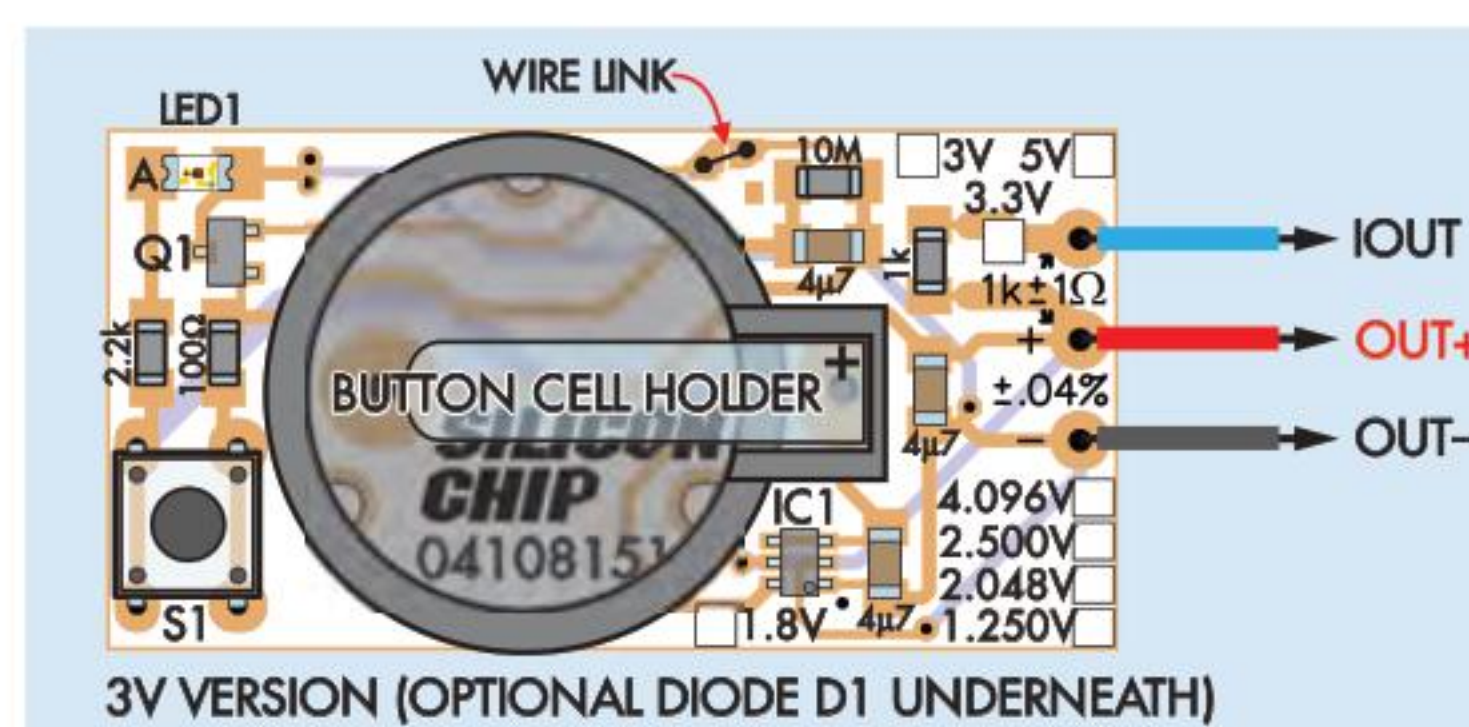
Most of the parts are SMDs and all but one have widely-spaced connections, making them easy to solder. The only slightly tricky one is IC1 but it really isn't that hard. It's best to solder the SMDs first, starting with IC1, before finishing with the through-hole parts. Refer to the appropriate overlay diagram – Fig.3 for outputs of up to 2.5V and Fig.4 for higher voltages.

First, it's a good idea to clean the PCB by swabbing it with a little alcohol (eg, methylated spirits) and a lint-free cloth. Also, applying flux to the SMD pads before soldering will make the job easier.

Melt a little solder onto one of IC1's six pads, then place the IC alongside and inspect it under magnification. There will be a small dot laser etched on top. This is the pin 1 marker and it goes towards the dot in the lower-right corner of the PCB. Orient IC1 as such, then heat the solder you added earlier and slide the chip into place using angled tweezers.

If it appears that IC1 is correctly placed, gently press down on the chip using the tip of the tweezers while heating the solder pad to ensure that it is sitting properly on the PCB. Then check under magnification that all six leads are centred over their pads.

Once it's in place, solder the leads on the opposite side (don't worry about bridging them), then go back and solder the three on the other side, including the one you tacked down earlier. Add some more flux, then clean up the joints using some solder wick. This will remove any bridges and should also ensure that a proper fillet has formed for each pin. Remove any flux residue using alcohol or a proper flux



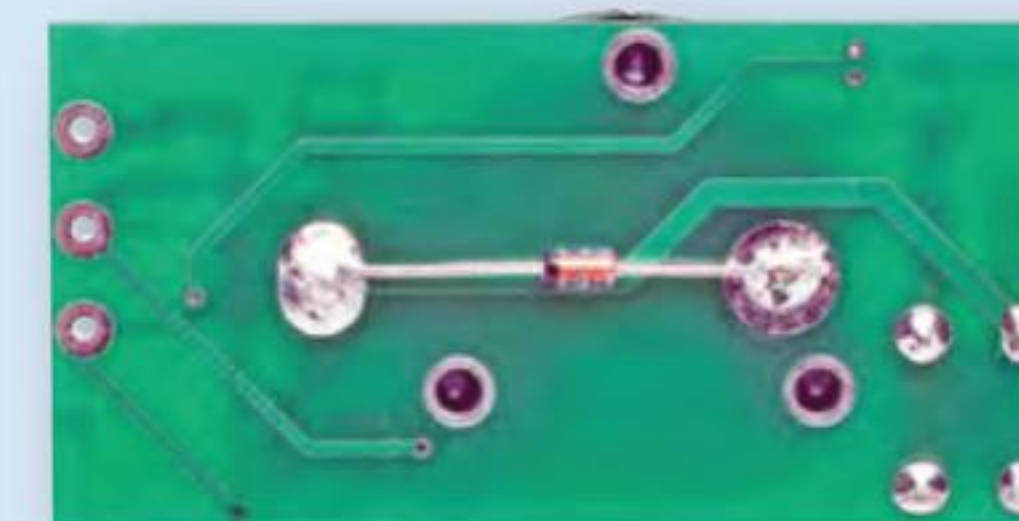
3V VERSION (OPTIONAL DIODE D1 UNDERNEATH)

Fig.3: follow this PCB parts layout diagram to build the versions with outputs up to 2.5V.

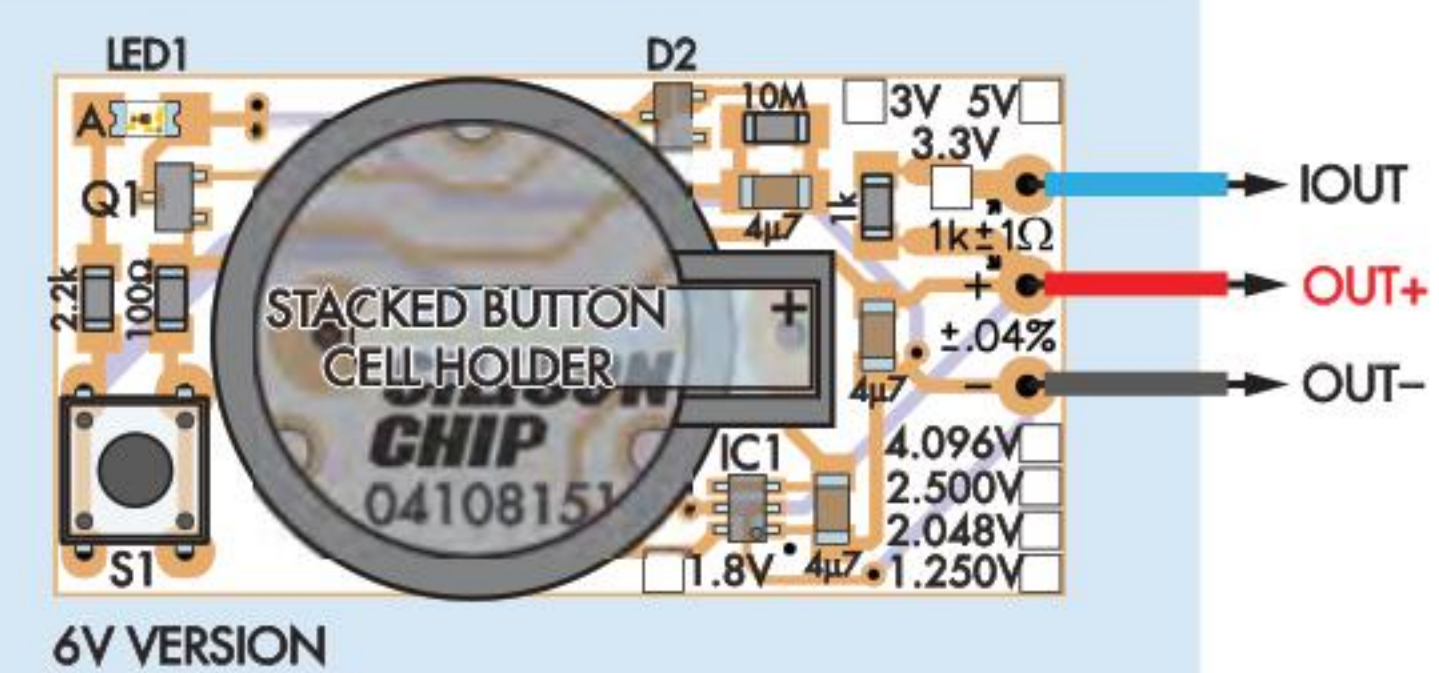


These two photos show an assembled 2.5V version

at left and a 5V version at right. The white screen-printed squares on the PCB let you mark the selected output voltage. It's a good idea to cover the completed assembly in clear heatshrink tubing.



Diode D1 in the 3V-powered version is optional. It can either be soldered across the battery holder on the underside of the PCB as shown at in the photo at left (cathode to positive) or it can be left out as shown at right (see text).



6V VERSION

Fig.4: this is the layout for the 3V to 5V versions. It includes diode D2 and a 2-cell holder.



solvent and then inspect with magnification to ensure all leads have been soldered properly. You can then move on to Q1 and, if you are building the 6V-powered version, diode D2. These are easier to solder as their leads are much further apart. As before, tack one lead down first, then check that the device is flat against the PCB and that its leads are properly lined up with the pads before soldering the remaining pins and refreshing the first one.

Be careful when fitting D2 as two of the pads are quite close together and easy to accidentally bridge. If you are not fitting D2 then these two pads should be shorted, either with a solder bridge or a very short length of wire (eg, made from a component lead off-cut).

You can now fit the resistors and capacitors in a similar manner, as shown in Fig.3 or Fig.4. The resistors will have their values marked on top (eg, 1001 = 1kΩ, 222 = 2.2kΩ), while the capacitors will be unmarked.

The last SMD is LED1 and you will have to check its orientation first. Set a

DMM to diode test mode and connect the probes to either end. If it lights up, the red probe will be on the anode and this goes in the corner of the board. Try to avoid heating it up too much as this can damage the LED. If it doesn't light up in either orientation, your DMM may not put out enough voltage in which case you'll have to use a small battery with a current-limiting resistor to determine the anode.

Once LED1 has been fitted, solder the tactile pushbutton and cell holder in place. In both cases, push them down hard to make sure they are flat on the PCB before soldering their pins. The cell holder will have three plastic posts which go through matching holes in the board. You may have to push fairly hard to get these to go in.

Optional diode D1

Finally, if building the 3V-powered version, you can flip the board over and solder the 1N4148 diode in place as shown on the above photo. Alternatively, you can leave this out if you're confident that you will always install the cell with the correct polarity. We're

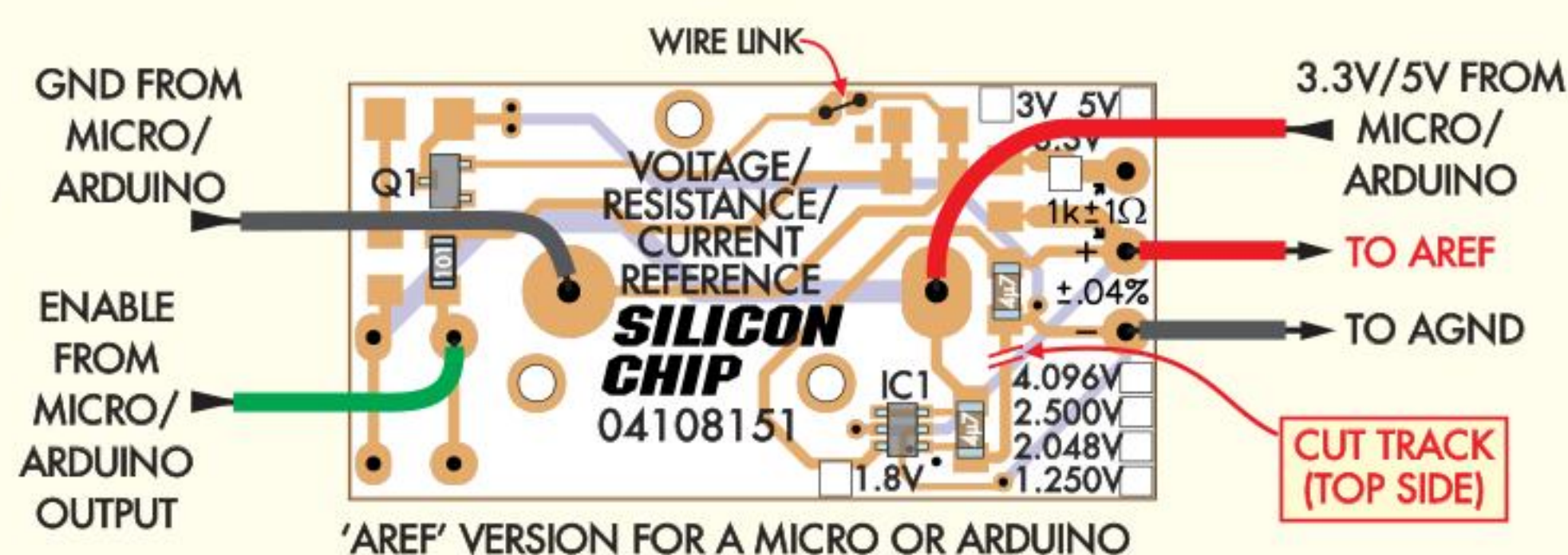
Using this board with an Arduino

If you're going to use this board with an Arduino, you can omit some of the parts. You certainly won't need the cell holder or pushbutton switch as power will come from the Arduino board itself. You could also leave off MOSFET Q1 and short it out if you don't need the micro to be able to switch the reference voltage on and off.

For now though, we're assuming this is useful, so Fig.5 shows how you can wire it up. The reference IC runs off 5V from the Arduino, which means you can't use the 5V reference but any of the others should be OK. The 'enable' line can be driven from one of the micro's outputs to turn the reference voltage on and off if required, or tied to the 5V rail to leave it permanently on.

Note the top layer track cut. This is important for maximum accuracy because without it, some of the supply current for

Fig.5: here's how to interface the unit to an Arduino for accurate ADC measurements. Note that you need to cut one of the PCB tracks.



the reference could flow via the analogue ground connection and cause a voltage drop across it, which would reduce the voltage seen by the micro's AREF pin.

When writing micro software, keep in mind that you will probably need to tell the ADC to use the AREF input as its voltage reference, rather than its AVDD supply rail voltage. Its full scale reading (eg, 1023 for a 10-bit ADC) will then indicate a voltage equal to (or just slightly less than) the new reference

voltage, rather than the 5V reading it would have indicated previously. This means that you may need to re-scale the results to suit the new ADC reference voltage.

Note that, if using the enable feature, the AREF pin will be pulled near the positive supply input when the reference is disabled. If the micro is running off 3.3V, it's likely it will not tolerate 5V on this pin, so be sure to either run the reference off the 3.3V supply or leave it permanently enabled.

not sure whether IC1 would survive a reversed cell; it might, due to the cell's internal resistance limiting current but we haven't been game to test this.

Finishing it up

Before placing the unit in its protective heatshrink sleeve, check that it's working properly. First you need to insert the cell (or cells). Check the polarity markers on the holder and cell(s) and then slide them into place.

Next, press S1 and verify that LED1 lights up, then goes out about 20s later. Note that if you touch the back of S1, your skin resistance can be enough to cause the unit to turn on briefly (this will be prevented once the heatshrink is in place). If LED1 does not turn on, it may have been fitted backwards or there could be a soldering problem. Press S1 and measure the voltage across LED1; if it is 2V or more, then LED1 is suspect, otherwise voltage is not getting to it for some reason.

Assuming LED1 lights up, measure the voltage between OUT+ and OUT- and verify that it's within specifications. If it seems low, press S1 again to ensure Q1 is fully on. Now is also a good time to use a marker pen to indicate which output voltage has been selected by marking one of the rectangles provided on the PCB silkscreen.

If you've fitted the 1kΩ resistor you can now check its resistance (between

OUT+ and IOUT) and verify the expected current by connecting a DMM set to measure milliamps between IOUT and OUT-. Note that the reading may be a little lower than expected; see the article on multimeter calibration in this issue for an explanation.

Now it's just a matter of sliding the clear heatshrink tubing over the unit and shrinking it down. Don't cover the test terminals right at the end of the board, although it's a good idea to insulate everything else. You can cut off any excess after shrinking. Note that if using the double-stack CR2032 cell holder, the tubing will be a tight fit but we managed to get it onto our prototype unit OK.

You're now ready to check and/or calibrate your multimeter(s) – see the accompanying article for details on doing this.

Other uses

This voltage reference may also be useful to allow very accurate voltage measurements to be made by microcontrollers, including those on Arduino boards.

The ADC in a microcontroller needs some sort of reference voltage. This is usually either its supply voltage (5V or 3.3V) or an internally generated reference. However, the internal reference is usually pretty inaccurate ($\pm 0.1V$ is typical) so in most cases you're better off using the supply voltage instead.

This also has the advantage that any voltage up to the supply voltage can be measured using the ADC.

However, you are then at the mercy of the accuracy of the regulator providing this supply. It may have a stated error of less than 1%; for example, the MCP1700 low-dropout linear voltage regulator has a typical tolerance of $\pm 0.4\%$. However it isn't uncommon for a linear regulator to have a much larger output voltage error such as $\pm 2\%$ or even $\pm 5\%$.

You also have to consider noise which may be injected into this rail from other devices drawing power in bursts, which can add an extra layer of uncertainty to ADC measurements.

It's much better to use an accurate voltage reference, normally fed into a dedicated pin on the micro (labelled something like 'AREF'). This will be free of noise and has the potential to have a much better defined voltage.

Note though that if you expect to make accurate measurements using an ADC fed with such a reference voltage, you will also need to make sure that any voltage dividers feeding ADC inputs use resistors with accurate values or that you have the ability to trim them. You will also need to keep the source impedance for the ADC inputs low, ie, don't use high values in the divider.

If in doubt, check the microcontroller's data-sheet.

By Nicholas Vinen

Using our Voltage/Resistance/
Current Reference for ...

Checking and calibrating multimeters

Do you trust your favourite multimeter? Does it always tell the truth? Maybe it doesn't! We tend to assume that the readings are accurate – but are they? They can drift off calibration quite markedly as the years pass. So how old is your multimeter and has it ever been checked? Now you can use our *Voltage/Resistance/Current Reference* to check your multimeter and if necessary, precisely calibrate it on DC voltage, current and resistance.

DEPENDING ON how much you paid for your multimeter, it may have been very accurate when new. But if it's a few years old, its readings might now be far from accurate. How would you know? You need to check it regularly against a reference to ensure it still meets its specifications.

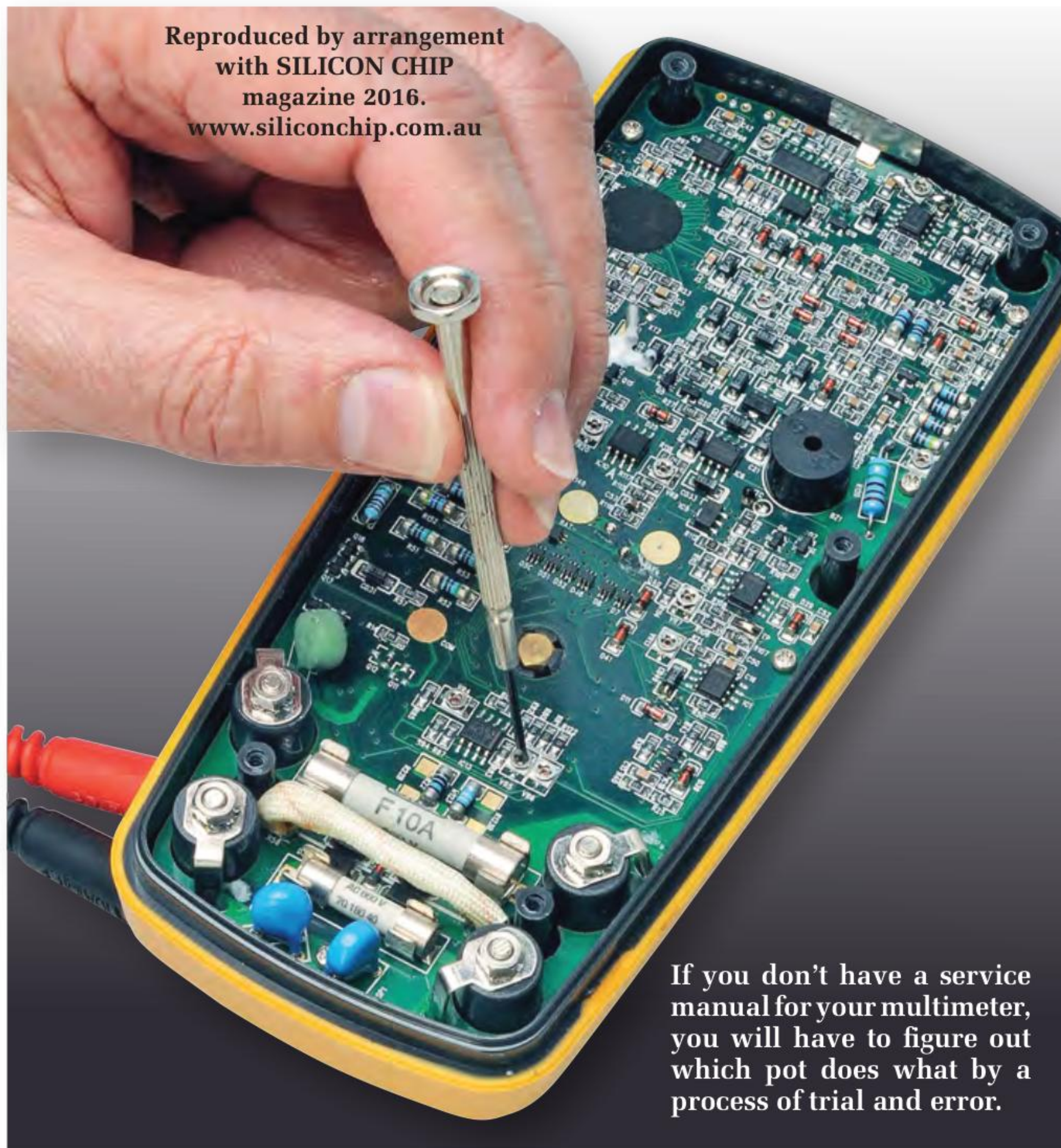
Ideally, you need several references; at least one voltage reference, one resistance reference and one current reference. Luckily, our *Voltage/Resistance/Current Reference* described elsewhere in this issue gives you all three, without you having to spend much money.

Of course, professional multimeter calibration operations need to have more complex equipment than this; they will have very accurate references that are themselves periodically checked against even more accurate devices and which can be adjusted to give voltages/currents/resistances that allow each range of a multimeter to be calibrated accurately. While our project only supplies a fraction of that, it's still a lot better than nothing.

So, assuming you've built our *Reference* module, how do you go about checking and calibrating your multimeter?

Checking voltage accuracy

First, if you have a very accurate multimeter that itself has been recently calibrated in an approved facility, you can use it to test your reference device and write down the measurements. If you don't have such a meter, you will simply have to assume that the *Reference* is perfectly accurate. If using our reference device, this is not a bad assumption – we measured the nominal 2.5V output error (on a 7.5-digit multimeter) as just -0.0005% (see photo overleaf)! Similarly, the nominal 1kΩ resistor was just 0.0134% low (compared to a 0.1% specification).



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If you don't have a service manual for your multimeter, you will have to figure out which pot does what by a process of trial and error.

First, set the multimeter to be calibrated into DC voltage measurement mode and set the range to the lowest range that will read the test voltage (if it's auto-ranging, it will select this automatically). Connect the probes to the OUT+ and OUT- terminals on the reference, switch it on and check the reading. If it is as close to the expected value as the meter can read, you know it's properly calibrated. You can reverse the probes and check that the negative reading is equally accurate.

You can also check that the reading is correct on higher settings, although the number of digits shown will of course be reduced so this will be a less accurate test. Still, it's worth doing. Note that a typical DMM typically only has a single adjustment for its DC voltage mode so if it is out in some ranges and not others, you probably won't be able to improve the situation without actually replacing some of its on-board multiplier resistors.

For checking lower voltage ranges, where the output of the reference will give an over-range error, you could

connect a resistive divider or potentiometer across the reference outputs, measure the resulting voltage on the higher range and then check that the lower range gives a similar reading.

Resistance mode

Checking the resistance reading is a similar process. Set the DMM on its lowest mode that can read $1\text{k}\Omega$ (this will usually be the $2\text{k}\Omega$, $4\text{k}\Omega$ or $5\text{k}\Omega$ range) and check that the reading is as close as possible to the actual value.

To check higher ranges, you could use the same resistor however it's better to pick a 'random' resistor which is just below the maximum you can read on the current range, note its value, then switch to the next higher range and verify that the reading is very close. You can then pick a resistor with 10x the value as the last and repeat the process up through the ranges.

Ranges below $1\text{k}\Omega$ can be checked using the same procedure, ie, pick a resistor with a value that's towards the upper limit of the lower range (eg,

180Ω), read this value on the same range as you used to check the $1\text{k}\Omega$ calibration resistor, then switch into the lower range and verify that the reading is correct. Then using a smaller value again, proceed down through the lower ranges.

Of course, the ideal situation would be to have a precision resistance box or a series of individual precision resistors but in practice, this cheaper method should do the job.

Ammeter checking

Testing an ammeter with the current source on our reference board is a little more involved because it has a high output impedance of $1\text{k}\Omega$. That means that, depending on the multimeter's range setting, its shunt resistance (and by implication, burden voltage) will affect the reading. However, you can easily compensate for this. The simplest method is to use a second multimeter to measure the shunt resistance of the meter being tested. The current is nominally 2.5mA for the 2.5V unit (5mA for the 5V unit, etc) so it should be suitable for testing both milliamp and microamp ranges (if present). To measure the shunt resistance, set the DMM on the range being tested, then connect the second meter in resistance mode between its current measurement terminals.

On our example meter, we got a reading of 101.28Ω on the microamps range, 2.2Ω on the milliamps range and 0.077Ω on the amps range.

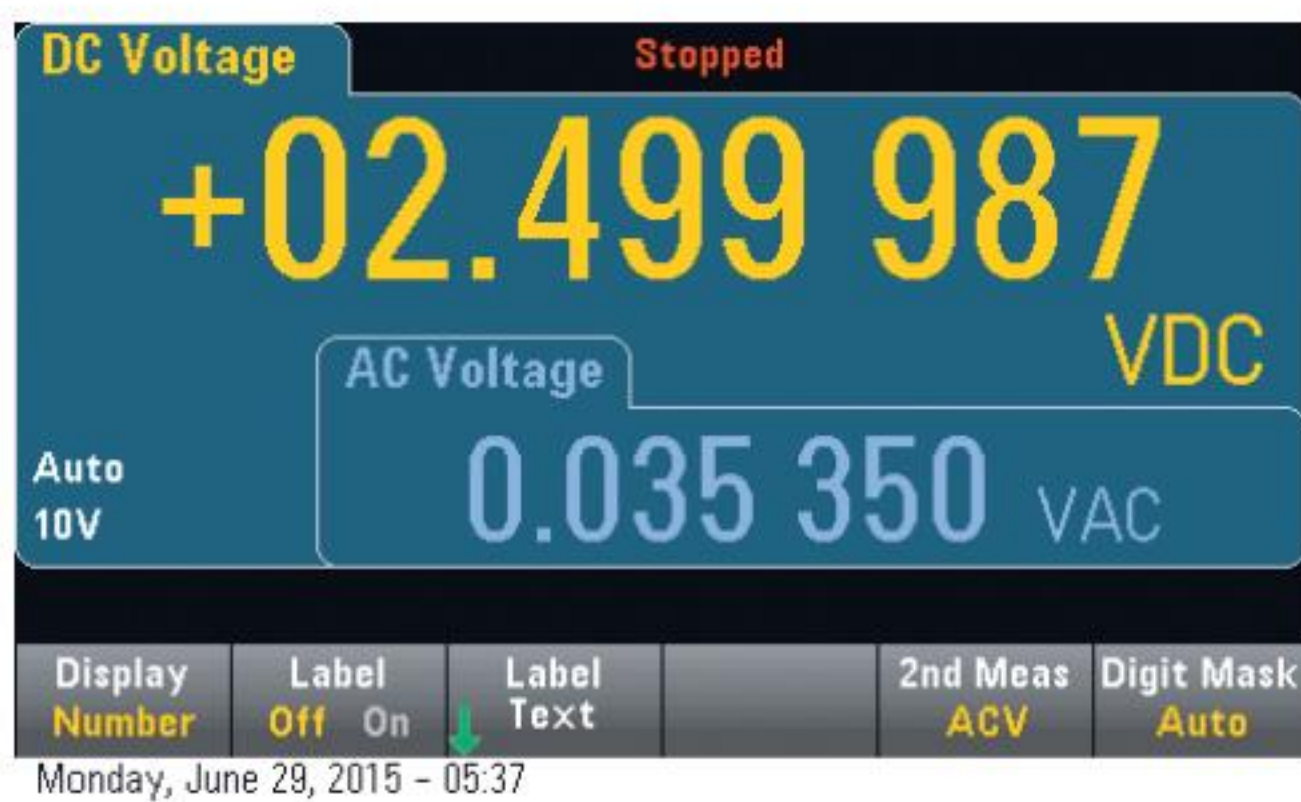
You can then calculate what the meter should read in each range by adding the calibration resistor value to the measured shunt resistor values and dividing into the reference voltage. In our case, our calibration resistor measured 999.866Ω (an error of just -0.013% !) and our reference voltage 2.499987V . Thus the expected readings for this meter are:

$$(a) 2.499987\text{V} \div (999.866\Omega + 101.28\Omega) = 2.270\text{mA in } \mu\text{A mode}$$

$$(b) 2.499987\text{V} \div (999.866\Omega + 2.2\Omega) = 2.4948\text{mA in mA mode}$$

$$(c) 2.499987\text{V} \div (999.866\Omega + 0.077\Omega) = 2.5\text{mA in A mode}$$

We didn't calibrate the example DMM but we did check its readings against these and got 2.270mA , 2.495mA and 2.5mA respectively. So it seems it doesn't need any adjustments for now.



While the nominal accuracy of the Maxim voltage reference is $\pm 0.04\%$, typically it will be much better, as demonstrated by this readout on a Keysight 34470A bench multimeter.

Performing calibration

If any of your checks give results with a noticeable deviation from the expected values (ie, more than ± 1), you will probably want to trim the meter to make it more accurate. Unfortunately, the procedure for doing this will be different for each meter, but there are some common steps.

First, you need to gain access to the trimpots on the PCB(s). This usually involves removing the back of the meter. If it is in a rubber holder, remove that first, then look for screws on the back. There are usually 2-4 screws holding the back on. You may also need to remove the battery cover first.

Usually, having undone the screws, the back will pull off quite easily. Modern DMMs are usually built on a single board but some may comprise two PCBs joined with headers or some other form of connector. Inspect the board(s) and locate any trimpots. We've seen as few as one and as many as 12!

If you're lucky, a service manual will be available on the internet for the model of multimeter you are calibrating which details the location and function of each trimpot.

For example, we had a look for the manual for our venerable Fluke 77 and

found it at the Fluke website. It confirms that the single trimpot is used to adjust the DC voltage reading. They suggest using a test voltage of 3V, which our reference board can provide with a suitable reference IC, however 2.5V should work fine too.

There should be a manufacturer-provided service manual available for just about every modern, brand-name DMM on the market. If you have a re-badged DMM, you may have some luck if you do a web search to find out the original manufacturer's model number for that product, then look up the service manual for that product.

If you can't find a manual for your meter but there's only a single pot, chances are that, like the Fluke 77, it adjusts the reading in the DC voltage mode. In that case, it's just a matter of hooking the reference up and tweaking it until the reading is correct. It may or may not also affect the current and resistance readings.

If there are multiple trimpots though, it's unlikely they will be labelled with anything other than a code. If you can't find a service manual for your DMM, you'll have to figure out what they do the hard way.

First, take a photo of the trimpots so you can see which position each one is in, in case you can't easily re-calibrate it later. Then, switch the meter into each mode in turn and adjust each trimpot. You'll probably have to hook something up to the input terminals in each mode to make changes apparent. Once you figure out what a given trimpot adjusts, write it down and move onto the next mode.

Hopefully, by the end of this process you have a full list of what each trimpot does. You'll also likely have a

meter that's way out of calibration! So calibrate the voltage, resistance and current pots using the previous explanations for how to check the operation of each mode. All you have to do is adjust the appropriate trimpot until each reading is correct (or as close as you can get it). If there are any pots that you can't calibrate, refer to the photo you took earlier to set them back into their original positions.

Note that in some cases, the pots themselves may not be directly accessible without removing the PCB or unplugging a sub-module, however you may find that you can adjust them from the back through holes in the board. Generally it's impossible to calibrate a multimeter without being able to observe the display while making adjustments so there's usually a way to do it with the board still in the case.

By the way, do not be tempted to use the 230VAC mains or other high-voltage sources to calibrate a DMM. It isn't safe to connect a DMM to the mains with the case open. You could get a lethal shock if you do.

Digital calibration

Some modern DMMs use digital calibration. There's no need to open the unit up; calibration is performed by manipulating the buttons on the front panel. For example, our Agilent U1252A and U1253B multimeters use this procedure.

In this case, you'll need the service manual for instructions on how to enter adjustment mode and perform the calibration. It's usually a similar process to adjusting trimpots, except that the up/down adjustments are made using pushbuttons. You'll still need the reference board to make the adjustments.

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Part 2: By JOHN CLARKE

Last month, we introduced our new *Driveway Monitor* and described how it worked. This month, we describe how to build, test and install it in your driveway. We also describe the various options so that you can build it to operate just the way you want.

BUILDING the *Driveway Monitor* is straightforward, with all parts mounted on two PCBs – both available from the *EPE PCB Service*) – a detector PCB coded 15105151 (104 × 78mm) and a receiver PCB coded 15105152 (79 × 47mm). As explained last month, the receiver PCB can be built in two versions. One version uses LEDs and a piezo buzzer to warn of vehicle arrival and exit, while the alternative version uses relays which are wired across the buttons of an external remote control PCB. This is then used to activate a remote-controlled mains switch.

Of course, there's nothing to stop you from building both versions of the receiver PCB if you want both sets of functions. As long as they're

paired to the detector unit, they will both be triggered whenever a vehicle is detected in the driveway.

Detector assembly

Construction can start with the detector PCB assembly – see Fig.12. Begin by installing the HMC1021 magneto-resistive sensor (Sensor1) at centre-left. This is a surface-mount device (SMD) and is soldered to matching pads on the top of the PCB.

To install it, first centre it on its pads making sure it is correctly oriented, then tack solder one of the corner pins. That done, check the alignment, adjust it if necessary and solder the remaining pins. The first pin can then be refreshed with some extra solder.

Don't worry if you get any solder bridges between the pins when soldering the device in. It can easily be removed afterwards using no-clean flux paste and solderwick. Check the connections under a magnifying glass to ensure that all the pins have been correctly soldered.

Once Sensor1 is in place, the resistors can be installed – you should check each one using a digital multimeter before soldering it in place. Be sure to fit the correct value at each location.

Resistor R1 (top left) is normally shorted out by a track on the underside of the PCB. As stated last month, this resistor is omitted if you will be charging the NiMH cell from a solar panel. Alternatively, you will have to

cut the track and fit this resistor if you intend using a 12V or 9V DC plugpack to charge the cell instead of using a solar panel.

A 220Ω 1W resistor should be fitted for a 12V DC plugpack, while a 100Ω 1W resistor is used for a 9V DC plugpack. Don't forget to cut the PCB track underneath the resistor – a section of the track has been thinned so that it is easy to break.

The next step is to fit the two links and their ferrite beads to the right of Sensor1. It's basically just a matter of inserting a length of tinned copper wire through each bead, then bending the leads down on either side so that they go through the holes in the PCB.

Follow with the two 1N4004 diodes (D1 and D2), taking care to ensure they go in with the correct polarity. An IC socket should then be fitted for PIC microcontroller IC2, after which you can solder IC1, IC3 and REG1 directly to the PCB (or you can install them in IC sockets). Be careful not to get these three 8-pin devices mixed up.

The seven PC stakes can now be installed on the board. Five of these are located at the TP 5.5V, TP GND, TP1, Vout (next to IC2) and ANT (for the UHF antenna) positions, while the other two are fitted between coil L1 and REG1 to terminate L1's leads.

Now for the capacitors. Fit the ceramic and MKT polyester types first, then install the five electrolytics. Note that the 470μF and 220μF values must be low-ESR types. Make sure that all the electros are correctly oriented.

MOSFETs Q1 and Q2 are next on the list, along with transistors Q3 and Q4 and regulator REG2. Be careful not to get the MOSFETs mixed up – Q1 is an IRF540 N-channel type, while Q2 is an IRF9540 P-channel device.

There are three trimpots on the PCB and these can now be installed. VR1 is a 500Ω trimpot and may be marked as '501', while VR2 and VR3 are both 10kΩ trimpots and may be marked as '103'. Be sure to push them all the way down onto the PCB before soldering their leads. LED1 can then be soldered in place with its anode lead (the longer of the two) going to its 'A' PCB pad.

Follow with the 3-way DIL header. This part is installed to the right of IC2, with the shorter length pins going into the PCB. CON1, the 2-way screw terminal block, can then go in with its wire entry holes towards the left.

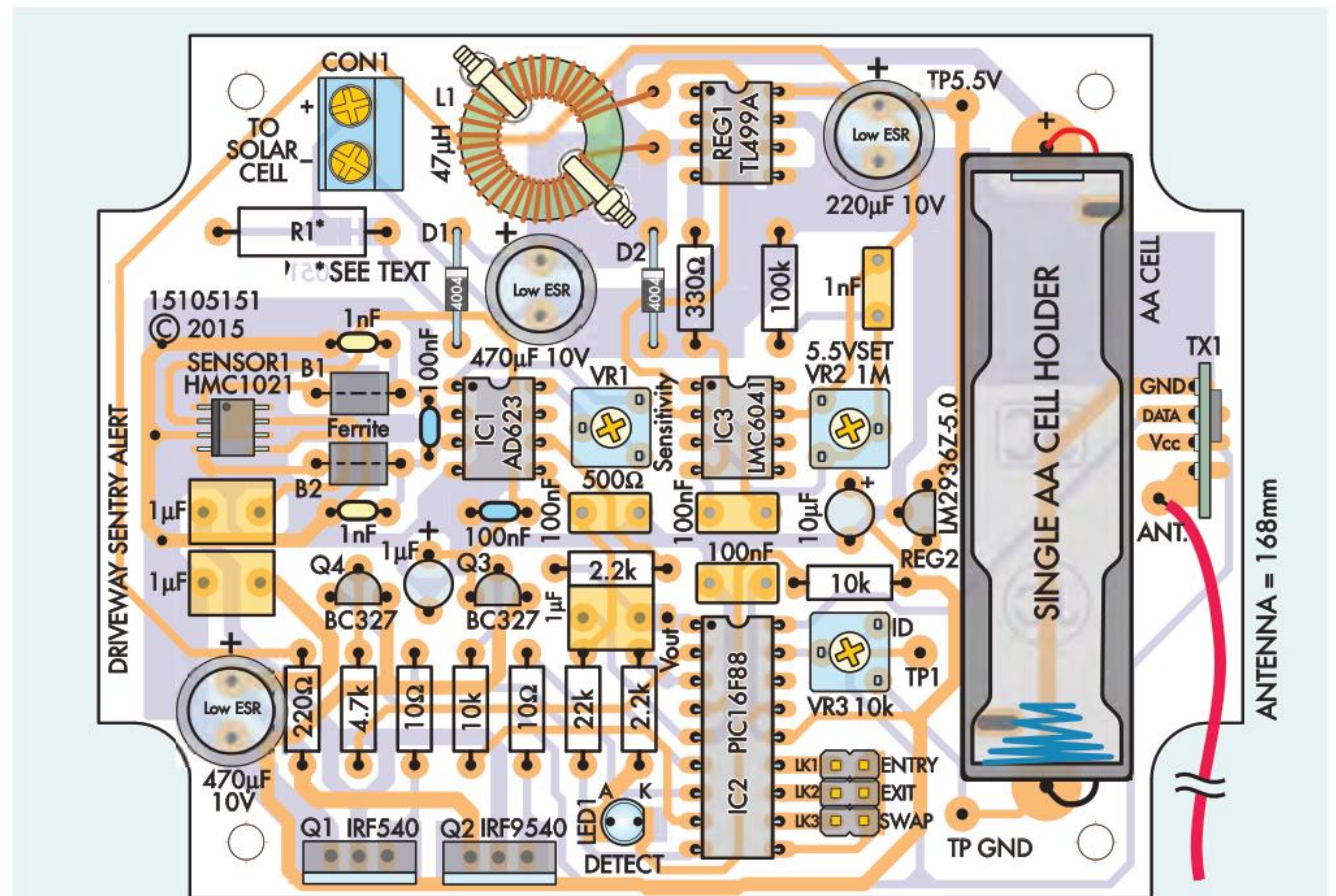
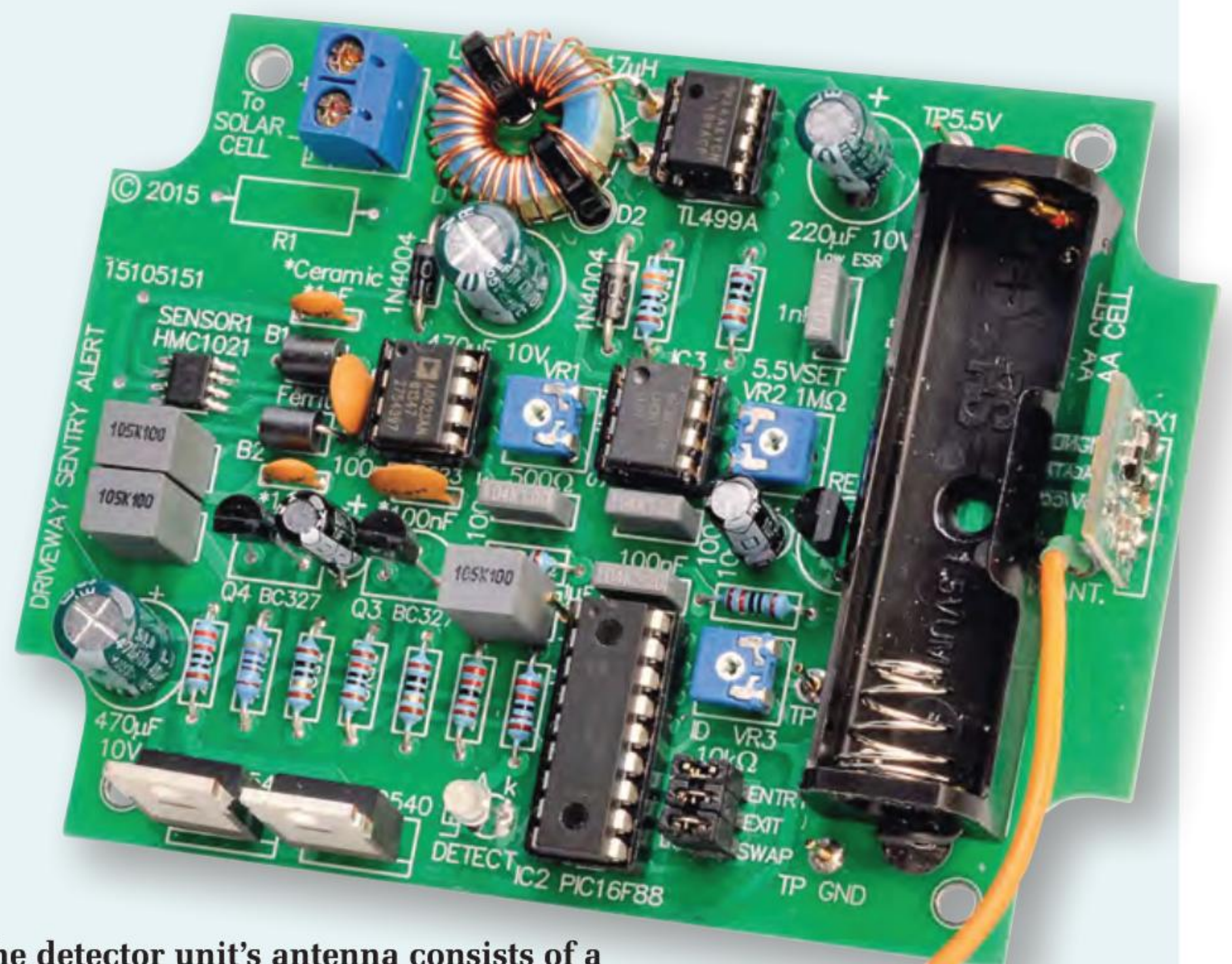


Fig.12: install the parts on the detector PCB as shown here, starting with the HMC1021 magneto-resistive sensor. Note that resistor R1 is omitted if you are charging the AA cell from a solar panel (see text).



The detector unit's antenna consists of a 168mm length of insulated hook-up wire. This should be fitted with a short length of heatshrink tubing at its far end so that it cannot short against any parts on the PCB.

Winding the inductor

Inductor L1 is wound on a powdered-iron toroid core using 32 turns of 0.5mm enamelled copper wire. Wind the turns on neatly in a single layer around the core (see photo), then trim

and strip the wire ends of the enamel insulation. The leads are then soldered to the coil's PC stakes, after which the toroid is secured in place using two cable ties that loop through adjacent holes in the PCB.

Constructional Project

The detector PCB assembly can now be completed by installing the cell holder, the UHF transmitter module and the antenna. The battery holder must be oriented as shown and is secured to the PCB using two self-tapping screws. Its leads are then cut short and soldered to their PCB pads at either end of the holder, with the red wire going to the '+' pad and the black wire to the 0V pad.

Take care with the orientation of the UHF transmitter module. Its pin designations are marked along one edge and it's just a matter of fitting it to the PCB with its antenna pin towards the bottom edge of the PCB (ie, towards the negative end of the cell holder).

The antenna consists of a 168mm length of insulated hook-up wire. Solder it to the antenna (ANT.) PC stake, then cover the connection with a short length of 1mm-diameter heatshrink tubing to prevent the lead from breaking at the solder joint.

Fitting it in a case

The completed detector PCB can now be fitted inside a standard IP65

polycarbonate case measuring 115 × 90 × 55mm. This requires no preparation apart from drilling a 12.5mm-diameter hole in one end to accept a 3-6.5mm cable gland to feed through the wiring from the solar panel (or from a plugpack).

This hole is positioned 25mm up from the outside base of the case and is centred horizontally. Use a small pilot drill initially, then carefully enlarge the hole to size using larger drills and a tapered reamer until the gland fits.

That done, the PCB assembly can be lowered into the case and secured using four M3 screws that go into the threaded corner bushes. The Neoprene seal for the lid then needs to be placed inside the surround channel and cut to size. Note that the join in this seal must be along the lower, longer edge of the lid (the detector unit is later installed with the longer edges of the box running horizontally, so that the PCB sits vertically to ensure maximum sensor sensitivity).

If you only require a UHF transmission range of 40m or less, then the antenna wire can be positioned inside the case (see photo). Make sure that the the end of the antenna cannot short against the PCB or any of the parts (fit some heatshrink tubing over the end to insulate it).

Alternatively, for longer transmission ranges of up to 200m, the antenna wire can be fed out through a small hole in the bottom edge of the box and this hole sealed with silicone to keep water out.

Solar panel

A free-standing solar panel garden light will typically cost £1-2, with better quality units coming in at around £5. This will include the required solar panel, a single NiMH cell and (typically) a white 5mm LED. However, the NiMH cell is usually an AAA type and so won't be usable. Even if an AA cell is fitted, it

will invariably be a low-cost (read low-quality) unit and you will be better off discarding it and buying a new one.

One problem is that the step-up voltage regulator on the detector board will not initially operate if the NiMH AA cell is discharged. That means that the cell must be charged before testing the unit.

If you don't have a suitable NiMH charger, then the solar panel can be used to charge the cell. It's simply a matter of removing the AAA cell and the white LED from the garden light, then running leads from the solar panel to the detector PCB and installing the AA cell in its holder. Note that the solar cell must be in sunlight in order for charging to take place.

Alternatively, you can temporarily run the leads from the solar cell to an external cell holder. The detector PCB can then be temporarily fitted with an alkaline AA cell for testing.

Detector PCB set-up

Having installed the detector PCB in its case, it's time to make a few adjustments. Just follow this step-by-step procedure:

- 1) Adjust trimpot VR1 to mid-setting and set VR2 and VR3 fully anti-clockwise.
- 2) Install IC2 in its socket, making sure that it's correctly oriented. Fit the other ICs and REG1 if you've installed sockets for these as well.
- 3) Fit the AA cell to its holder, then measure the voltage between the TP5.5V and GND PC stakes and adjust VR2 for a reading of 5.5V. If you cannot get sufficient voltage, it may be due to the AA cell. Check the cell voltage and if that's OK, try momentarily removing the cell and reinserting it so that REG1 starts properly.
- 4) Check that there is +5V at pin 14 of IC2 (this could be from 4.85-5.15V, depending on the particular regulator used for REG2).
- 5) If all is OK, the unit should now be ready to detect magnetic field variations (about 10s after the cell is installed). Orient the unit so that the PCB is vertical and check that the bicolour LED lights red or green if the unit is rotated by a few degrees. The LED should then go out again after a brief period if the unit is kept stationary.
- 6) Check that the unit can detect a pair of steel pliers if they are passed



◀ Left: inside the solar garden light. Its AAA cell and white LED must be removed and the cable from the detector unit soldered across the battery holder contacts.

close to the sensor. LED1 should light red if the pliers are passed in one direction and green in the other.

Note that, in practice, IC1's output should not swing too close to the supply rails. Output swings close to 0V ($<0.3125\text{V}$) or close to 5V ($>4.6875\text{V}$) will be indicated by the bicolour LED alternately flashing red and green at a 1s rate.

If that happens, there is either a high magnetic field in the vicinity of the sensor (eg, a magnet) or IC1's gain is set too high by VR1.

Diagnostic mode

Now install a jumper between LK2 and LK3, as shown on Fig.13. This sets the unit into diagnostic mode which is used for testing only, since other circuit functions are disabled and the circuit draws a relatively high current while it's in place.

By installing this link, variations in IC1's output can be monitored using a multimeter connected between Vout and TP GND. You can either rotate the detector unit or swipe a pair of steel pliers close to the sensor and then check that the DMM shows the resulting variations in IC1's output.

Note: this mode is not used when adjusting IC1's gain. That's done later by trial and error when the detector unit is installed in the driveway.

Setting the identity

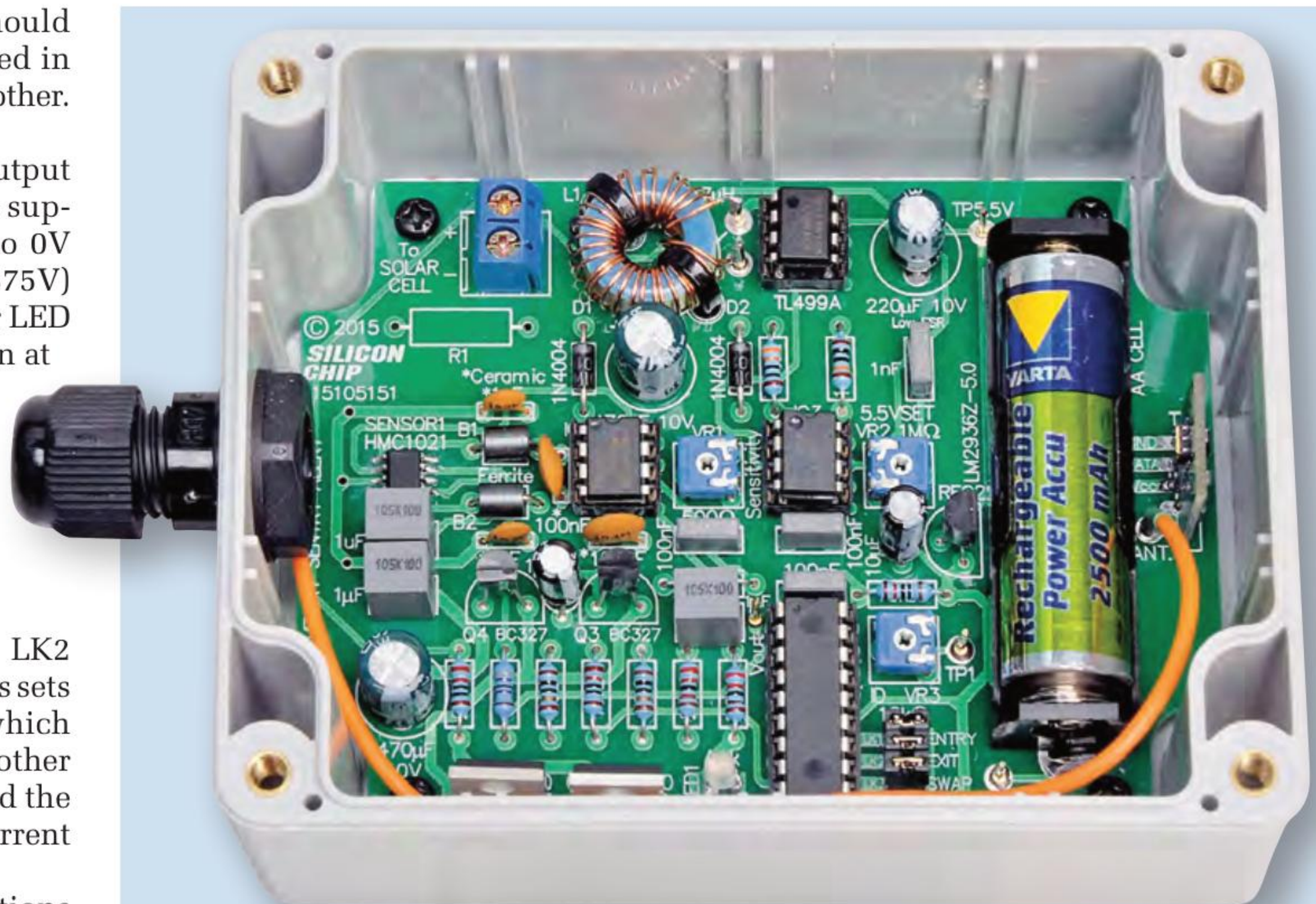
The diagnostic mode is also used when adjusting identity trimpot VR3. If you have only one detector unit, simply set VR3 fully anticlockwise for a UHF transmission identity of '1'.

If you have more than one detector unit, they will each need a different identity to avoid interference. It's just a matter of installing the diagnostic link and adjusting VR3 so that the voltage at TP1 matches an identity setting voltage, as shown in Table 3.

Linking options

As mentioned last month, jumpers LK1-LK3 determine the information that's encoded into the UHF transmission sent to the receiver – see Fig.13. As shown, LK1 is installed for arrival (entry) notifications, while LK2 gives departure (exit) notifications. Depending on your requirements, you can either install both these links or leave one or the other out.

For example, let's say that you build



The detector PCB is secured to integral threaded corner posts inside its IP65 case. Be sure to install the NiMH cell the right way around and note that the cell must be charged before testing the unit.



Our prototype had the cable gland fitted to a side panel but fitting it to the bottom panel would be preferable in many installations.

the relay version of the receiver and you want to trigger a remote-controlled mains switch for a set period of time only when a vehicle arrives. In that case, you would install a jumper on LK1 to signal vehicle entry but no jumper link for LK2 (exit).

If you want to trigger the remote for both directions, install both LK1 and LK2.

LK3 is installed if the arrival and departure indications are incorrect (it simply swaps them around), while installing a jumper between LK1 and

Constructional Project



The detector unit must be attached to a non-metallic post or wall adjacent to the driveway. You can either mount the solar panel on top of the detector or leave it in the garden light housing as shown at right. Make sure that the solar panel is mounted in a sunny location.

LK2 sends a non-directional indication to the receiver.

Note that the link settings operate in exactly the same way for both receiver versions.

Detector unit installation

The detector unit can be installed alongside the driveway on a post or wall.

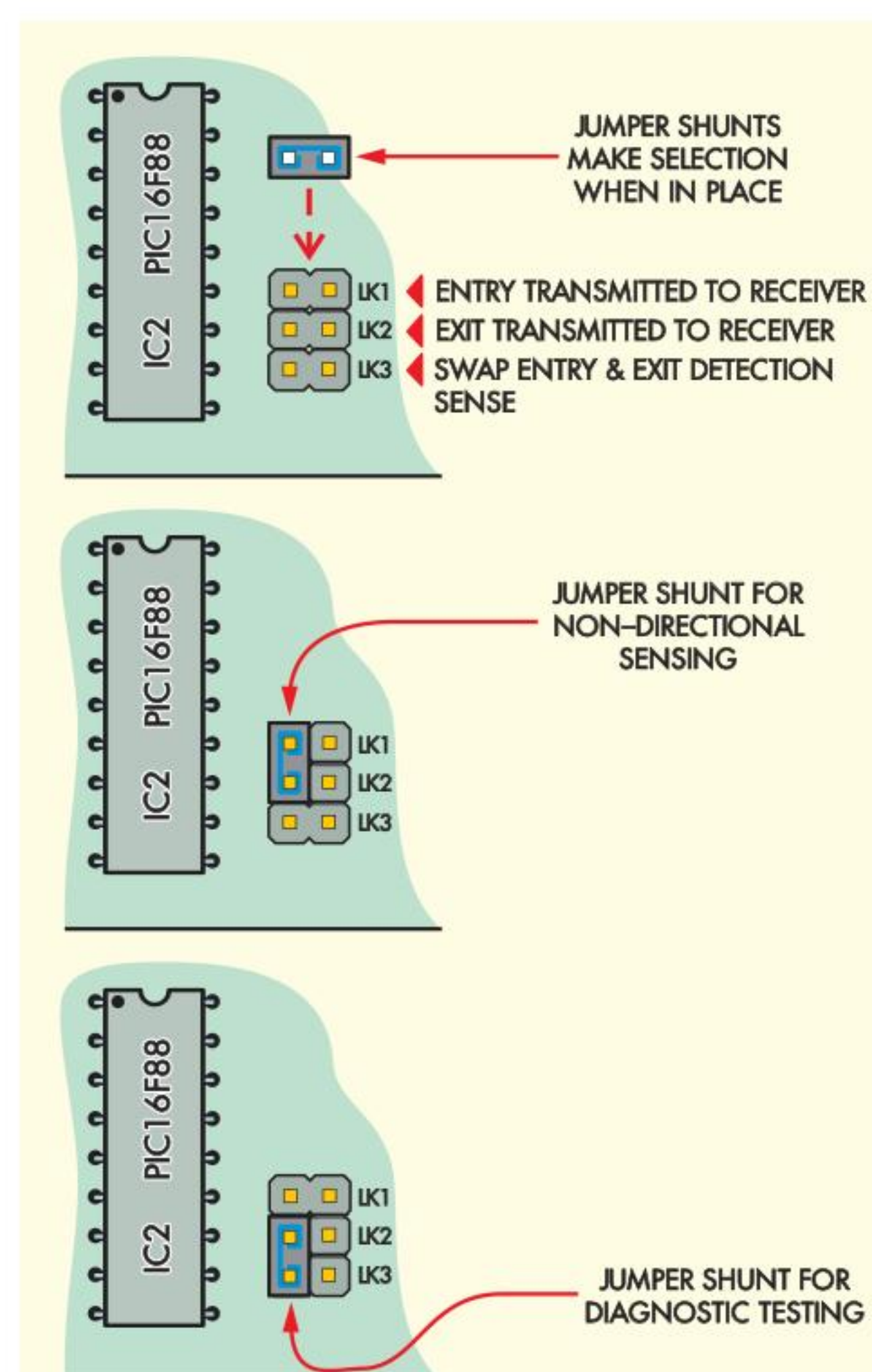


Fig.13: this diagram shows the linking options for the detector PCB. The diagnostic jumper between LK2 and LK3 is for test purposes only.

Before mounting it, ensure the unit will reliably detect a passing vehicle.

That can be done by temporarily placing the unit on a wooden box or stool so that it's about 60-80cm above ground (ie, so that it lines up with the metal body of a car). If you like, you can leave the diagnostics jumper in place so that you can check that Vout varies as a vehicle passes by.

If it does, remove the diagnostics jumper and check that the detector unit lights the green LED for one direction of the vehicle and the red LED for the other direction. If the vehicle isn't reliably detected, adjust sensitivity trimpot VR1 clockwise to increase IC1's gain (but don't set VR1 fully clockwise). Conversely, wind VR1 anti-clockwise to decrease the gain if the red and green LEDs in the bicolour LED flash alternately at a 1s rate.

In practice, VR1 should be set somewhere between fully anticlockwise and about three-quarters clockwise in order to achieve reliable detection.

During this test procedure, the detector must be kept still, otherwise it will detect changes in the Earth's magnetic field due to its own movement. If that happens, the tracking thresholds then need to be readjusted so that they sit equally above and below the amplified sensor voltage and this could take some time (eg, over a minute).

If you want the tracking thresholds to readjust faster, you can remove the

AA cell for a few seconds and then re-install it. By doing this, the thresholds will readjust within 10s. Another way is to change LK3 (ie, either install the jumper or remove it). Each time LK3 is changed, the detection thresholds re-track within 10s.

Once it's working, the detector unit can be permanently mounted using the holes provided in the box corners (these holes are accessible when the box lid is removed). These holes could either be used to directly secure the unit or you could use them first to attach a bracket (preferably made from non-magnetic material) which is then attached to a wall or post.

Connecting the solar panel

The solar panel is connected to the detector via a length of figure-8 cable. This cable is passed through the cable gland, either in the side or bottom edge of the case, and terminated in screw terminal block CON1. Be sure to connect the cable with the correct polarity (the red wire that's connected to the solar panel is positive).

Be sure also to disconnect the solar panel from the LED inside the garden light fixture. The fixture should then be installed nearby in a sunny part of the garden, to ensure that the solar panel gets full sun during the day.

If that arrangement isn't convenient (eg, you don't have a nearby garden bed), then the solar panel can be removed from the light fixture and mounted separately. It may even be possible to mount it on top of the detector unit using a suitable non-metallic bracket, as shown in the photos.

Finally, use neutral-cure silicone to seal the wire entry into the cable gland to keep moisture out of the case. The same goes for any other possible water-entry locations (eg, screw mounting holes for brackets).

Receiver assembly

Fig.14 shows the assembly details for the two receiver versions. Version 1 has the reed relays to trigger a remote control PCB, while Version 2 has the piezo buzzer and LED indicators for audio/visual warnings only.

As mentioned earlier, if you want both sets of functions, you will have to build both versions and set them to the same identity as the receiver. Note that the LEDs and piezo buzzer must be omitted if you build the relay version (Version 1), while the relays and

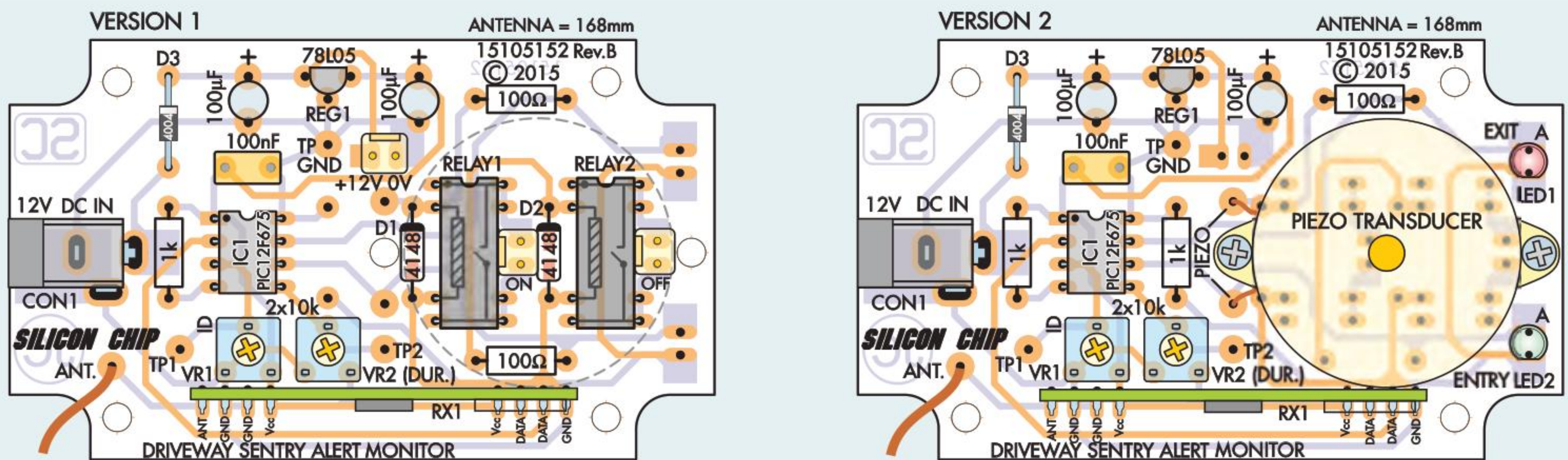
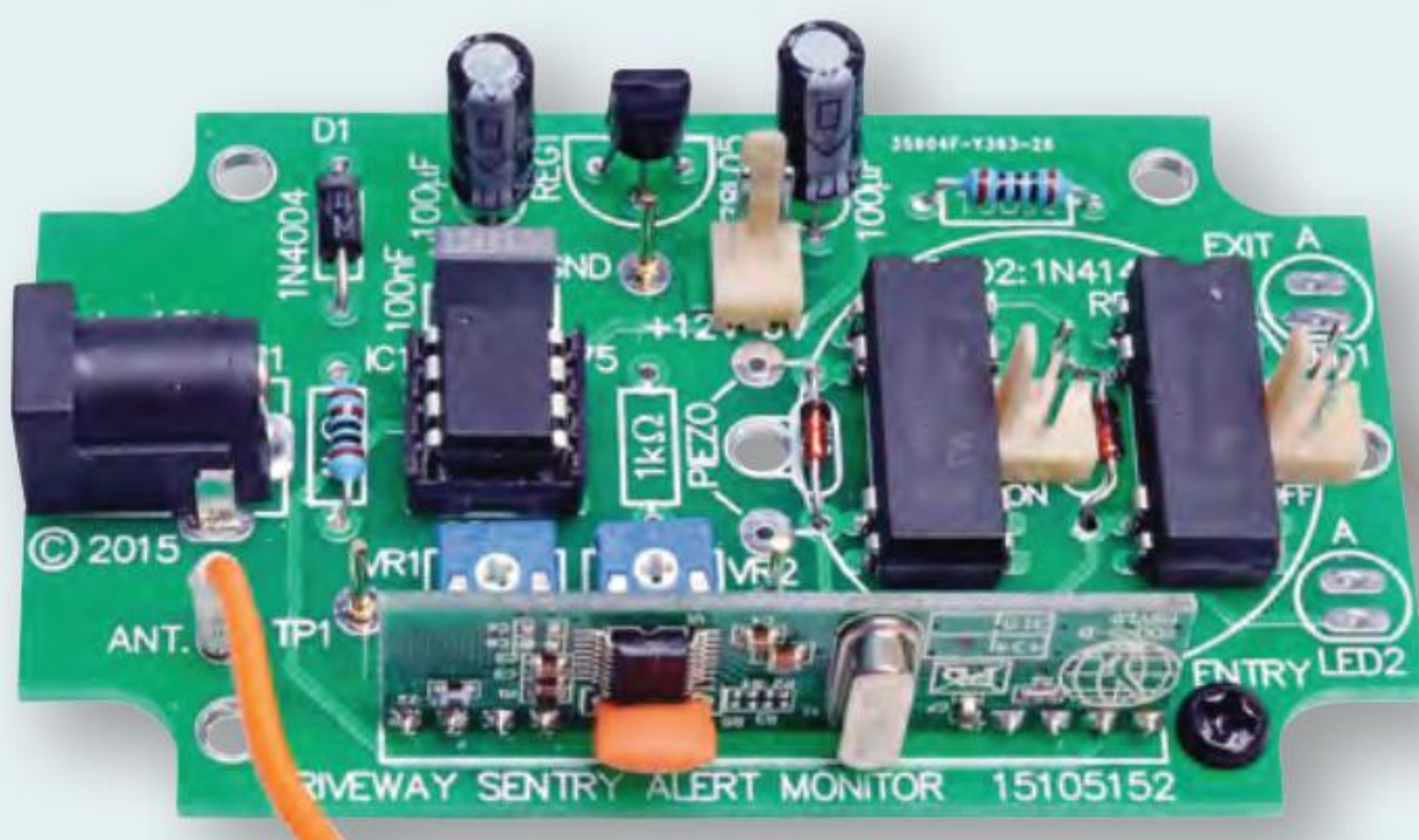
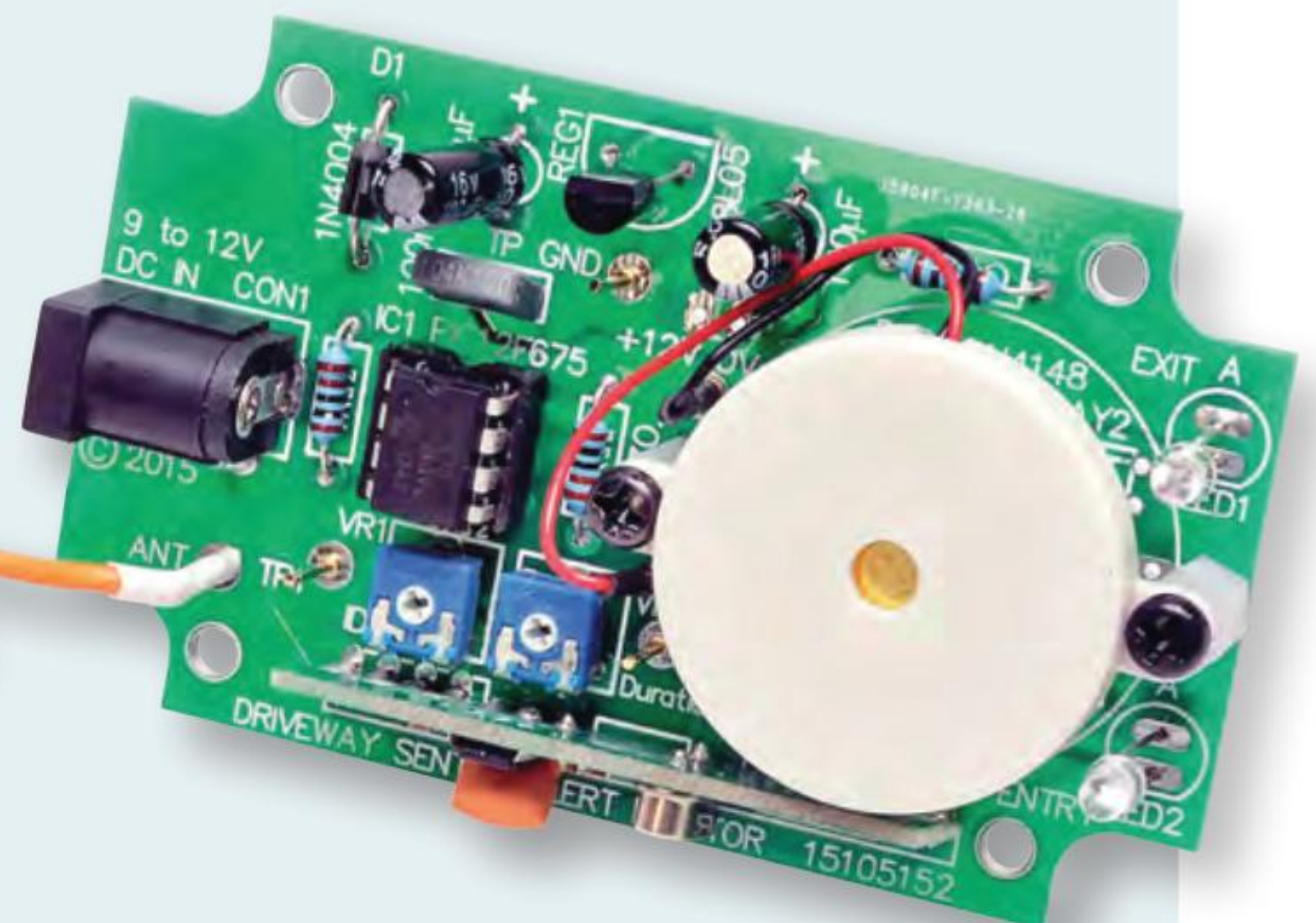


Fig.14: the PCB parts layouts for the two receiver versions. Build Version 1 if you want to activate the buttons on a separate remote control PCB (eg, to control a UHF remote mains socket). Alternatively, build Version 2 if you only require an audio/visual warning when a vehicle passes the driveway detector unit.



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These views show the two fully-assembled receiver versions. Make sure that all polarised parts are correctly oriented and fit heatshrink over the lead connections to the PC stakes to prevent the wires from breaking at the solder joints.

diodes D1 and D2 are omitted from Version 2.

In most cases, it's just a matter of selecting which version you want to build and assembling the board to match its layout. Install the resistors first, then install diode D3 (1N4004). D1 and D2 (1N4148) should then be fitted if you are building Version 1. **Note that D2 must be installed about 3mm proud of the PCB, since it needs to be later pushed to one side to make room for a polarised 2-way header.**

The PC stakes are next on the list and these are installed at TP GND, TP1, TP2 and the antenna (ANT.) terminal. If you are building Version 2, two extra PC stakes can be fitted to terminate the piezo buzzer leads (or you can elect to solder these leads directly to the PCB).

The capacitors can be installed next. Note that for Version 2, the electrolytic capacitors must be no more than 14mm high so that they don't foul the lid of the case.

An 8-pin socket should now be fitted for IC1. Make sure that the socket sits flush against the PCB before soldering its pins, then install REG1 (78L05). The two relays can then be fitted if you are building Version 1. Check that these are oriented correctly (ie, notched ends aligned as shown on Fig.14).

Version 1 also requires three polarised pin headers. Install these now, bending diode D2's leads to the right, as shown in one of the photos to clear the header that's fitted between the two relays.

Follow with the DC socket and trim-pots VR1 and VR2. The two LEDs can then be installed for Version 2 (red for LED1 and green for LED2). These two LEDs must be installed with 11mm lead lengths, so that the tops of their lenses are 16mm above the PCB. That's easily done by pushing each LED down onto an 11mm-high cardboard spacer that's slid between its leads before soldering it in place.

Piezo transducer mounting

The piezo transducer used in Version 2 mounts on two M3 × 9mm tapped spacers. These spacers are secured to the PCB using M3 × 6mm screws. The piezo transducer is then secured in place, again using M3 × 6mm screws. You will have to drill out the transducer's mounting tab holes to 3mm diameter to accept the M3 screws.

Once the transducer is in place, trim its wires to about 25mm, slip some 15mm lengths of 1mm-diameter heatshrink tubing over the wires and solder them to the adjacent PC stakes. The heatshrink can then be slid over the soldered connections and shrunk down to prevent the wires from breaking.

UHF receiver

You can now complete the PCB assembly by installing the UHF receiver module and the antenna. It must be oriented with its antenna pin to the left (ie, towards the DC socket). As with

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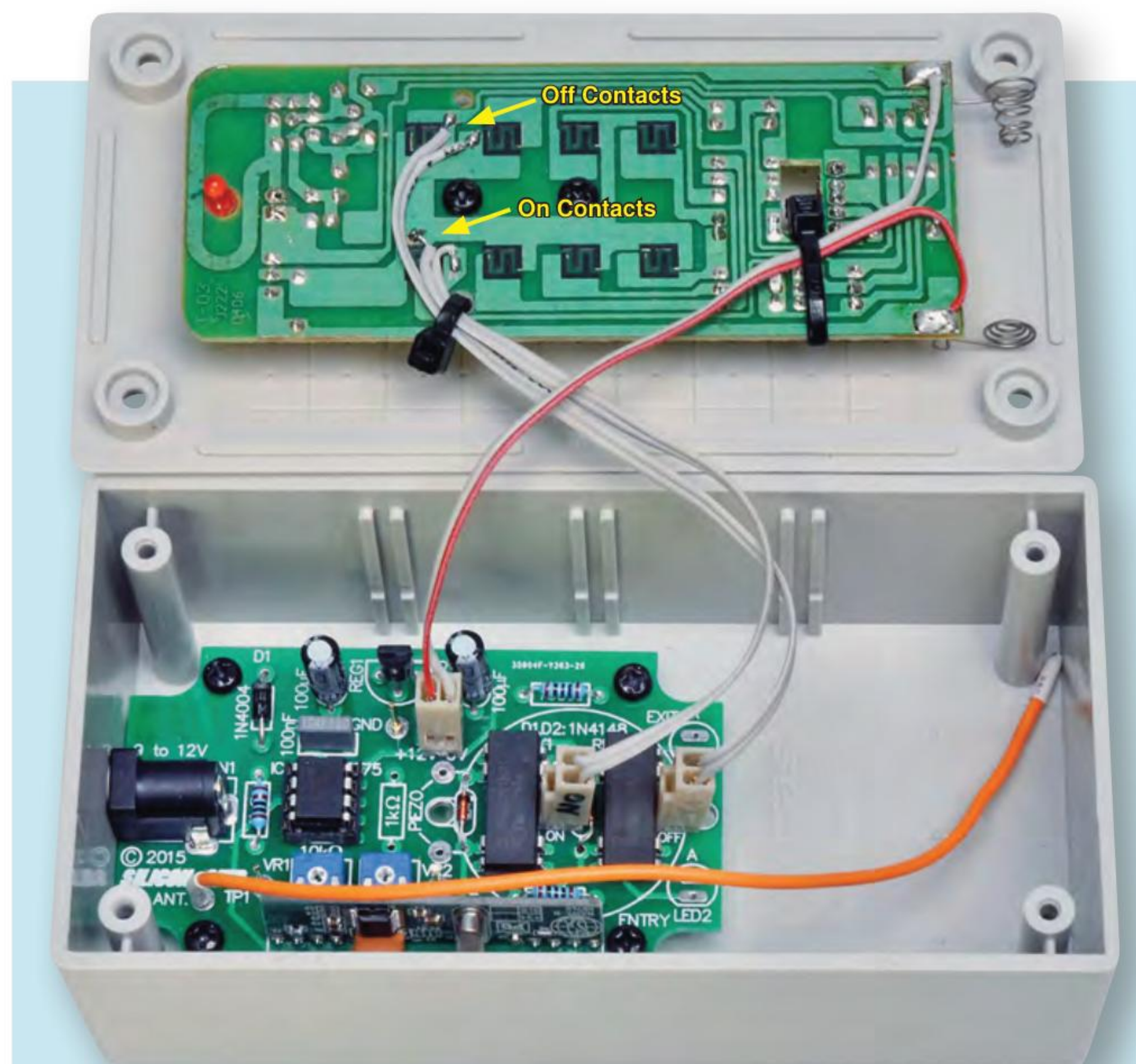


Fig.15: this photo shows the wiring connections between Version 1 of the receiver PCB and the remote used for the Jaycar UHF mains socket. You will need to scrape away the solder masking from some of the pads on the remote PCB before soldering the leads.



A UB3 plastic case is used to house Version 1 of the receiver PCB and its companion remote PCB. The front-panel label is optional.

Modified sampling rate for identities 5-8

Recent testing on the *Driveway Monitor* has shown that a vehicle can, on rare occasions, slip past the sensor unit undetected. To do this, the vehicle has to be travelling at over 20km/h and it has to pass the detector between the 300ms sampling intervals.

This will not be a problem for most household driveways, but it could be a problem on rural driveways where speeds can easily exceed 20km/h.

To overcome this problem, we have increased the sampling rate to 150ms for identities 5-8 (ie, where TP1 is set for over 2.5V). So, if vehicle speeds are likely to exceed 20km/h, set the unit to one of these higher identities.

Identities 1-4 retain the standard 300ms rate. A disadvantage of the 150ms sampling rate is that quiescent current from the AA cell increases from about 3mA to 6mA.

the transmitter, the pin designations are printed on the module.

Once it's in place, solder a 168mm-long insulated wire to the antenna PC stake. The soldered connection should then be covered with heatshrink tubing to prevent the wire from breaking.

Version 1 final assembly

The Version 1 PCB receiver assembly is housed in a UB3 plastic case (130 × 68 × 44mm) with the PCB from the mains socket's remote. We'll describe how the two are wired together shortly, after the PCBs have been mounted in position.

The receiver PCB mounts in the base of the case on M3 × 6mm tapped spacers. That's done by first placing the PCB inside the case with the DC socket flush against one end, then marking out the four corner mounting holes. These holes are then drilled to 3mm and countersunk on the outside of the box using an oversize drill.

A 9mm hole must also be drilled in the end of the case to provide access to the DC socket. This hole is positioned 17mm up from the base of the case and centred horizontally. You will also have to drill a small hole in this end of the case for the antenna lead if you require a range greater than about 40m.

Once that's been done, the spacers and the receiver PCB can be secured in position using M3 × 10mm countersink screws and nuts. The antenna lead can be either run around the inside perimeter of the case or fed out through its exit hole. As with the detector unit, make sure that the end of the antenna cannot short against the PCB or any of the parts.

The next step is to mount the remote control PCB. Suitable remote-controlled mains sockets include the Jaycar MS-6142 and MS-6145 units and the Altronics A0340.

Before removing the remote's PCB module, the remote control mains socket should be set to operate as described in the instructions. This will familiarise you with the way the unit works and allow you to set the channel number and test its operation.

Once you've done that, the hand-held remote can be disassembled. The Jaycar remote has one screw located beneath the battery cover and when this is removed, the two halves of the remote case can be cracked open along the sides with a screwdriver. Similarly, the Altronics remote has two screws under the battery compartment lid

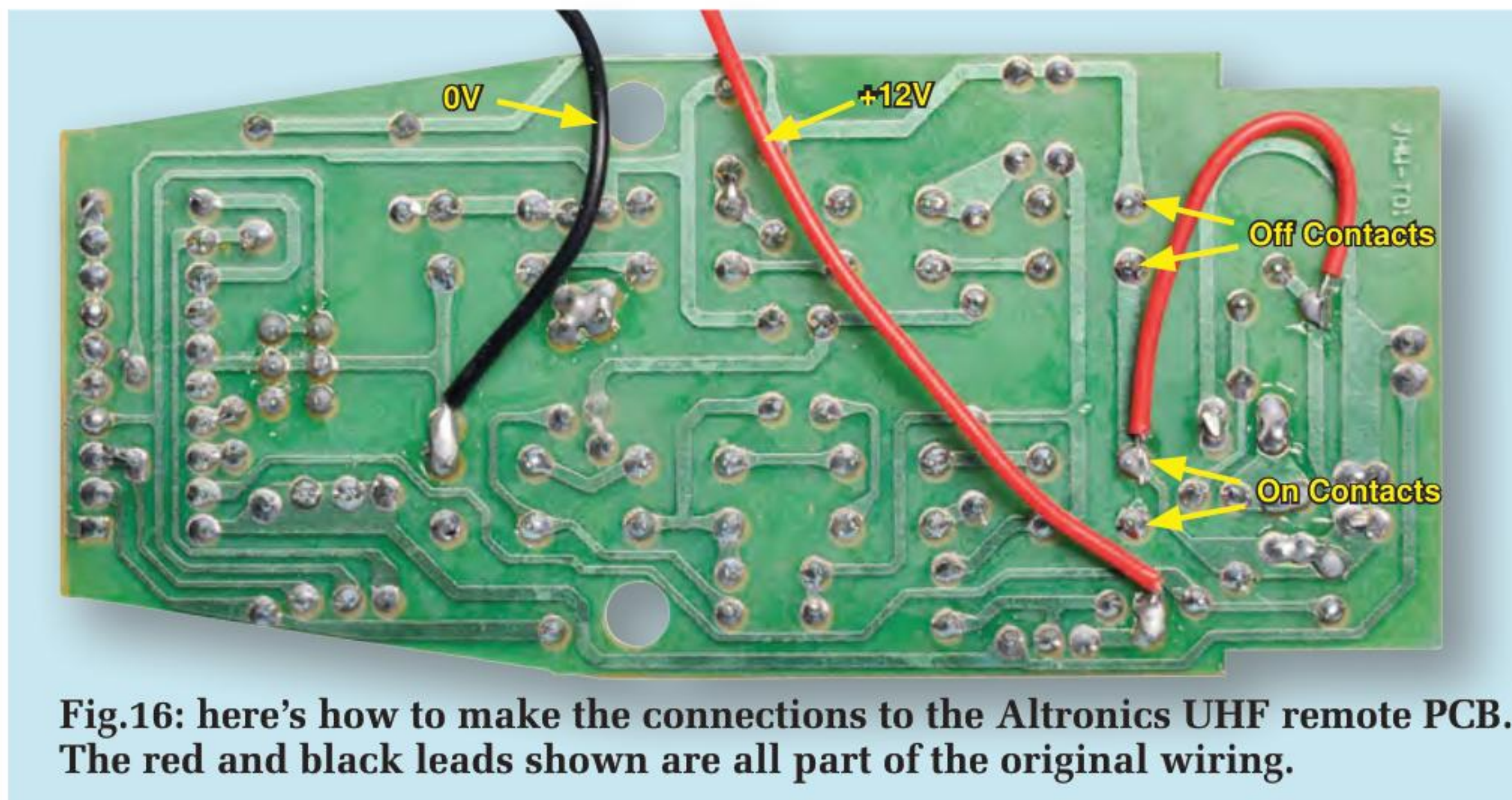


Fig.16: here's how to make the connections to the Altronics UHF remote PCB. The red and black leads shown are all part of the original wiring.

and removing these allows you to split the case.

It's then just a matter of removing the remote PCB and connecting leads from the polarised headers on the receiver PCB. The 12V header is wired to the remote's supply rails, while the other two headers are connected to the remote's on and off button contacts for the selected channel. That way, when the Driveway Monitor is triggered, one reed switch closes briefly to turn the remote-controlled mains switch on. The other then closes briefly a few minutes later to turn the mains switch off.

The leads from the headers can be run using 120mm lengths of light-duty hook-up wire. At the header end, it's just a matter of crimping the wires into the crimp lugs and then lightly soldering them before pushing them into the header shell until they are captured by the tag springs. Use red and black leads for the 12V header and make sure you get the polarity correct.

Figs.15 and 16 respectively show the connections to the Jaycar and Altronics remote PCBs.

On the Jaycar unit, it will be necessary to scrape away the solder masking from the PCB before soldering the connections. Once all the wires are in place, fit cable ties around the switch wires to prevent them from pulling away from the PCB. It's also a good idea to use neutral-cure silicone or hot-melt glue to hold the wires in place.

In the case of a doorbell remote, it's simply a matter of wiring the first reed switch across the switch contacts. This reed switch could also be used to trigger a burglar alarm.

The remote PCB is mounted on the underside of the case lid. Both remotes have two holes that can be used as

mounting points (note – the Jaycar unit's holes will need to be enlarged to 3mm. In each case, the unit is mounted on M3 × 9mm tapped spacers and secured using M3 × 6mm machine screws.

We used countersink-head screws for the lid so that the heads sit flush with the panel to allow a front-panel label to be attached. Position the mounting holes so that the remote PCB is centred on the lid, then mount the PCB in position and plug the various leads into their corresponding sockets on the receiver PCB.

Version 2 final assembly

The Version 2 receiver is housed in a UB5 case (83 × 54 × 31mm), making it more compact than the Version 1 unit. In addition, no mounting hardware is required for Version 2 since the PCB simply clips into slots in the integral side channels in the case.

Before installing the PCB, you will have to drill a 9mm hole for the DC socket. This should be positioned 20mm up from the base and centred horizontally. As with Version 1, drill a small hole for the antenna lead if you require a range greater than about 40m (ie, up to 200m). You can then clip the

Unit pairing

A feature of the *Driveway Monitor* is 'pairing' – each detector and receiver pair is given a unique identity. This allows up to eight different pairs to operate in the same vicinity, which means you can have multiple *Driveway Monitors* installed on your property.

Pairing is set by adjusting trimpots VR3 in the detector unit and VR1 in the receiver to give matching voltage readings at their respective test points – see text and Table 3.

receiver PCB into position and either feed the antenna wire through its hole or run it around inside the case.

Finally, three holes have to be drilled in the lid – two for the indicator LEDs and one directly above the piezo transducer to let the sound out. You can either copy and use Fig.17 as a drilling template or you can simply measure the hole locations and then mark their positions on the lid (the artwork is also available for download as a PDF file from the *EPE* website). Drill 3mm holes for the LEDs and a 6mm hole for the piezo transducer.

Testing (both versions)

Before applying power, make sure that IC1 is out of its socket and that all parts are correctly oriented. That done, apply power from a 12V DC plugpack and check that there is 5V between pin 1 of IC1's socket and the GND PC stake (4.85V to 5.15V is acceptable). A reading below 4.85V could mean that there is a short circuit somewhere or an electrolytic capacitor could be the wrong way around.

If the 5V supply is correct, disconnect power and plug IC1 into its socket (make sure it's correctly oriented). Once

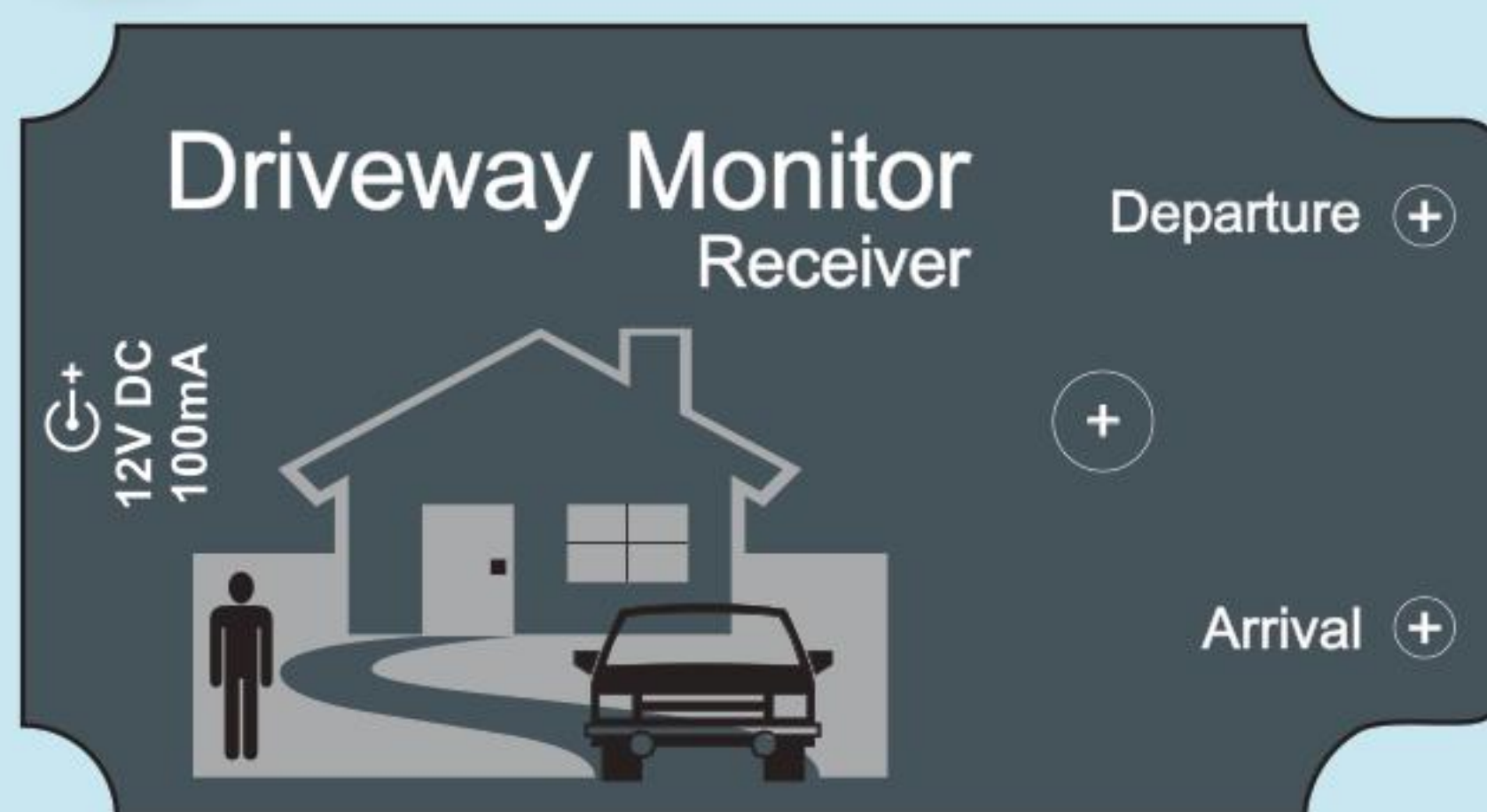
Table 3: Identity voltage settings			
Identity	Minimum Setting	Maximum Setting	Recommended
1	0V	0.47V	0-0.31V
2	0.78V	1.09V	0.94V
3	1.41V	1.71V	1.56V
4	2.03V	2.34V	2.19V
5	2.66V	2.97V	2.81V
6	3.28V	3.59V	3.44V
7	3.91V	4.21V	4.06V
8	4.53V	5V	4.69-5V

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Version 2 of the receiver is housed in a UB5 plastic case. You will need to drill holes in the lid for the LEDs and piezo buzzer.

Fig.17: this full-size artwork can be used as a drilling template for the Version 2 case lid. You can either copy it or download it as a PDF file from the EPE website.



Front panel labels

The front-panel labels are optional. They can be made by downloading the relevant PDF files from the EPE website and then printing each one as a mirror image onto clear overhead projector film (use film that's suitable for your printer). By printing mirror images, the toner or ink will be on the back of each film when it's fitted. The labels can be secured using clear silicone adhesive.

Alternatively, you can print onto a synthetic Dataflex sticky label if using an inkjet printer or onto a Datapol sticky label for a laser.

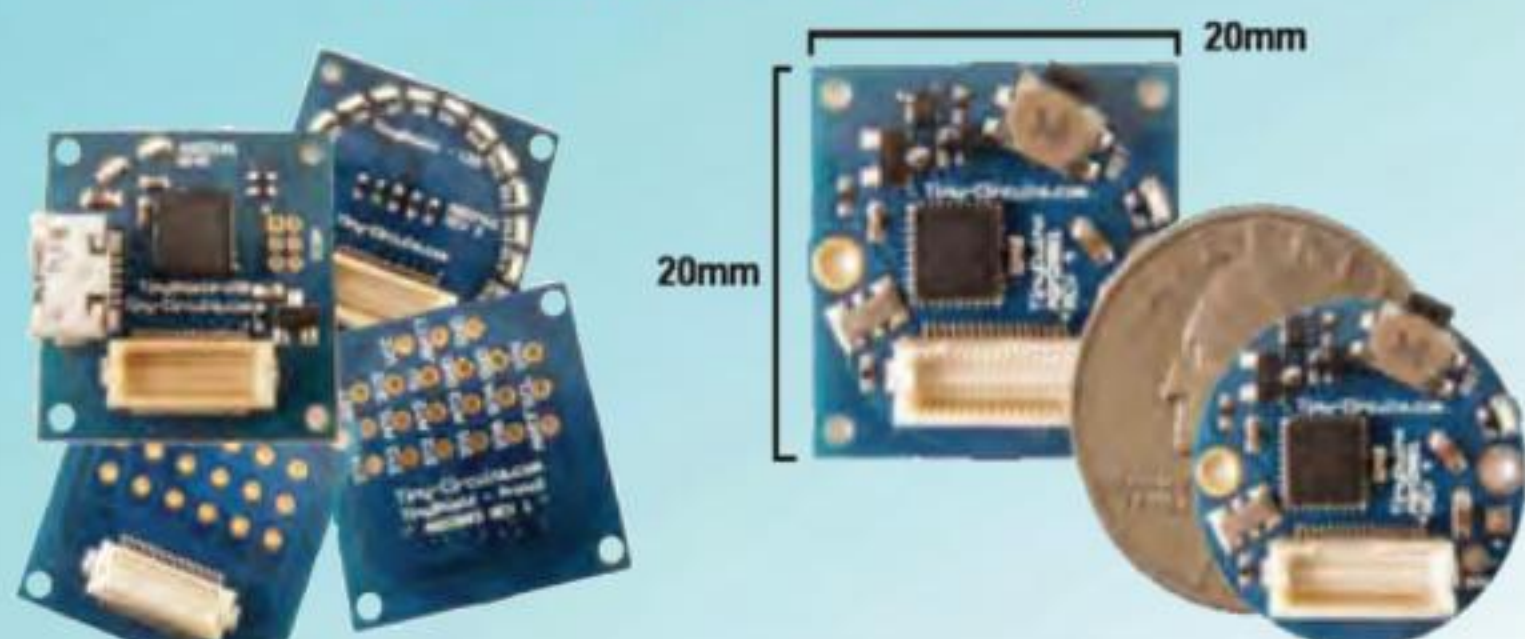
(1) For Dataflex labels, go to: www.blanklabels.com.au/index.php?main_page=product_info&cPath=49_60&products_id=335

(2) For Datapol labels go to: www.blanklabels.com.au/index.php?main_page=product_info&cPath=49_55&products_id=326

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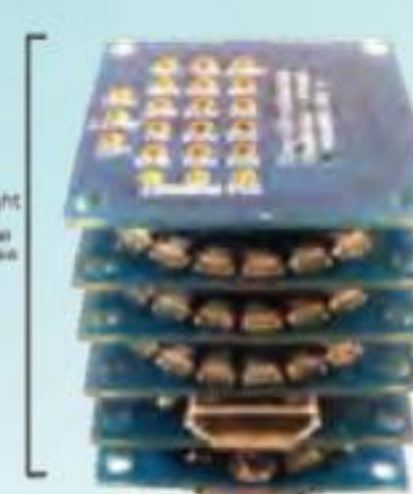
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it's installed, reapply power and adjust VR1 to set the receiver's identity by monitoring the voltage on TP1.

Typically, VR1 is set fully anticlockwise to select identity 1. If you require a different identity (eg, to match a second detector unit), set it to match the detector as shown in Table 3.

Trimpot VR2 sets the alert duration. For Version 1, this is the time period between when relay 1 briefly turns on and closes the remote's ON contacts to when relay 2 briefly turns on and closes the remote's OFF contacts (ie, it determines how long the remote mains socket is switched on). This time duration ranges from about 20s when VR2 is fully anticlockwise to about five minutes when VR2 is fully clockwise.

You can quickly set the duration by monitoring the voltage between TP2 (ie, VR2's wiper) and TP GND. Adjust VR2 for 5V on TP2 for five minutes, 2.5V on TP2 for two and a half minutes and 1V on TP2 for one minute...

Alternatively, for Version 2, VR2 adjusts the length of the entry and exit tones from 1-5s. Each indicator LED then lights for the length of its corresponding tone and stays on for about 15s after the tone ceases.

All that remains now is to check that the unit is triggered whenever a car passes by the detector unit. If the unit fails to trigger or is unreliable, check that the detector unit is functioning properly as outlined in its installation procedure above. If that's OK, check that the detector and receiver identities match.

Finally, if you still have problems and the antennas are inside the cases, feed them outside and straighten them out to improve the range. They should also be oriented the same way; ie, both vertical or both horizontal.

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EVERYDAY PRACTICAL ELECTRONICS is offering its readers the chance to win one of 10 Microchip MPLAB Xpress Evaluation Boards. The new MPLAB Xpress Evaluation Board features an integrated programmer, a PIC16F18855 MCU and a mikroBUS header for system expansion with MikroElektronika's 180+ Click boards. The PIC16F18855 is a general-purpose 8-bit microcontroller that sports one of the largest selection of Core Independent Peripherals to date.

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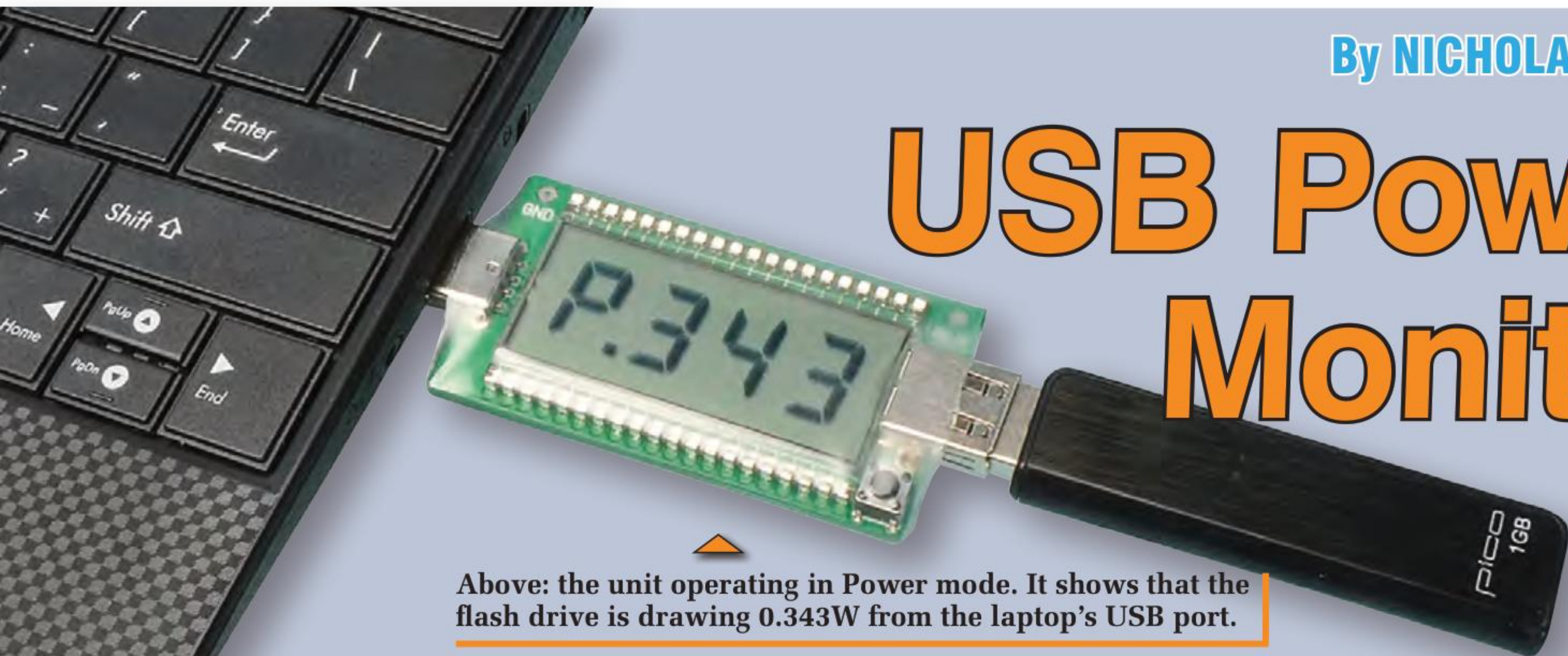
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By NICHOLAS VINEN

USB Power Monitor



Above: the unit operating in Power mode. It shows that the flash drive is drawing 0.343W from the laptop's USB port.

Curious about how much power your USB peripherals use? Perhaps you are building a USB device and want to check its consumption. Or maybe you want to figure out how many devices you can plug into an un-powered hub or what impact a USB device has on your laptop battery life. Build this USB Power Monitor and find out.

THIS SIMPLE, compact device connects in series with one or more USB devices and displays the current they are drawing at any given time. It can also show you the bus voltage and calculate the power consumption in watts. It's auto-ranging, so it will read down to just a few microamps and up to over an amp. Similarly, it will read out in milliwatts or watts. You can cycle the modes simply by pressing a button.

It uses a low value (50mΩ) shunt to measure the current so this will have little effect on the voltage received by the peripherals. The readings are displayed on a 4-digit LCD panel, similar to that used by digital multimeters. This is readable from a wide range of angles. Calibration is performed by the microcontroller the first time it is powered up, and can be repeated later to keep measurements as accurate as possible.

The whole unit measures 90 × 35 × 10mm and is encased in clear heat-shrink tubing. When plugged in, it's like a wide USB flash drive with an LCD on top. It can either go straight into a USB port or be connected via a USB extension cable. It can be used

with ports on either side of a laptop (using the display flip feature), although it's optimised for use on the righthand side.

USB power overview

The Universal Serial Bus consists of four lines per port: two for power (0V and 5V) and two differential signals for bidirectional data (D+ and D-). The supply is nominally 5V but due to imperfect regulation at the source and voltage drops across the wiring, a device can expect to receive between 4.4V and 5.25V.

A USB device is allowed to initially draw 100mA but can negotiate for more current; up to 500mA. With the nominal 5V supply, that means that no more than 2.5W can be drawn from any given port. Some (but not all) USB ports provide current limiting so that if too many devices are connected or if a device tries to draw too much power, the supply is cut and the port reset.

In practice though, certain devices such as portable hard drives will draw more than 500mA when they are first plugged in (eg, as the hard disk motor spins up) so the USB port current limit is not strictly enforced; many

ports will allow up to 1A or more to be drawn before shutting down. This is a low enough limit to prevent a short circuit from damaging the port but high enough that most connected devices should get enough power.

To complicate matters, multiple devices can be connected to a single USB port using a hub. The power drawn by an unpowered hub is its own operating power (usually ~50mW) plus that of all the devices plugged into it. You can see how you can easily exceed 500mA per port by plugging enough devices into a hub – you can even plug hubs into hubs!

Powered hubs are another matter; these have their own power supply (typically a plugpack) and so only a minimal amount of current is drawn from the upstream port.

Standby mode

When a computer enters standby or sleep (power saving) mode, it sends a signal to the connected USB peripherals to do the same. When in standby, they are expected to draw no more than 0.5mA (2.5mW). When the computer subsequently 'wakes up', it sends another signal to the

peripherals which can then resume normal operation.

When in standby, devices can wake up the host and this feature is most often used by USB mice and keyboards. Also, devices may go into standby mode if they are currently inactive; for example, a hub with no connected devices will generally drop into standby mode after a few seconds but will resume normal (higher power) operation if you plug a device into the hub.

So you can see how a USB power monitor has a number of useful applications. You can test devices to ensure that they do not draw more than 0.5mA in standby or 100mA before they have been configured. You can check the total power draw of a hub and its attached devices. You can even see how the power consumption changes depending on what the devices are doing, in real time.

Also, devices running from a portable computer's USB ports will cause its battery to discharge faster and you may wish to determine just how much effect this has on battery life. By measuring how many watts each device draws, you can divide this by the battery capacity in watt-hours to determine the proportion of battery charge those devices will deplete per hour of operation.

For example, say you have a 3G wireless Internet dongle and the USB Power Monitor tells you that it draws 2.5W while active. If your laptop has a 12V, 5Ah (60Wh) battery then this will drain $2.5W \div 60Wh = 4.2\%$ of the battery's capacity, per hour of use.

If your laptop normally lasts four hours on battery then it will typically draw $60Wh \div 4h = 15W$, so we can calculate that it will last $60Wh \div (15W + 2.5W) = 3$ hours 30 minutes with the 3G dongle connected and operating, ie, using the 3G dongle will reduce the battery life by 30 minutes.

Design

We have seen other designs for USB power meters and although we liked the concept, we weren't so impressed with the execution. While you can measure the current drawn by a USB device with just a USB plug, socket, shunt resistor, shunt monitor and panel meter, this approach is quite limited.

A typical panel meter has a full-scale sensitivity of 200mV, which

Features and Specifications

Measurement modes: current, voltage, power

Current resolution: 1 μ A (0-10mA), 1mA (10mA-1A+)

Voltage resolution: 10mV (4.4-5.5V)

Power resolution: 10 μ W (0-10mW), 1mW (10mW-1W), 10mW (1-5W+)

Current accuracy: $\pm 2.5\% \pm 0.1mA$ (mA range), $\pm 5\% \pm 10\mu A$ (μA range)

Voltage accuracy: $\pm 2.5\% \pm 10mV$

Power precision: $\pm 5\% \pm 0.1mW$

Temperature-related error: typically $< 1\mu A/^{\circ}C$

Load voltage drop: typically less than 50mV

Power consumption: 5.3mA/26mW

Other features: display flip mode, mode memory, digital calibration

means you can either measure up to 200mA with 0.1mA resolution or up to 2A with 1mA resolution. Really, we want to measure to at least 500mA and we want a minimum resolution of 0.1mA; preferably better at lower current readings. Our design, while a little more complex, does even better, with readings beyond 1A and a resolution of 1 μ A for readings below 10mA.

By using a microcontroller we can also add some extra modes such as voltage and power reading which just make it so much more convenient to use. We were also able to keep the unit fairly slim and compact, with large, easy-to-read digits.

Circuit description

Refer now to Fig.1 for the complete circuit diagram of the *USB Power Monitor*. All the parts shown mount

on a single double-sided PCB. USB plug CON1 goes into the computer or USB charger. Current then flows from its pin 1 (+5V) through the 0.05 Ω shunt resistor to pin 1 of CON2, the USB socket. Return current passes directly from pin 4 of CON2 (ground) to CON1.

The USB D+ and D- data signals pass straight through from pins 2 and 3 of CON1 to CON2, with the tracks running right across the PCB. They are close together so that any interference couples into both lines by a similar amount, preserving the integrity of the differential signal.

The 0.05 Ω resistor is a special type with 'Kelvin connections', ie, it has four terminals, each pair of which are internally joined to the resistive element. This prevents resistance in the solder joints from affecting current

USB power delivery enabled devices

Virtually all USB ports supply a nominal 5V and this project relies on that fact. USB 3.0 has introduced ports able to supply up to 900mA (which this device can handle), increasing the power delivery from 2.5W per port to 4.5W. But for a lot of devices, that still isn't enough.

Hence, a new specification has been developed. Called 'USB Power Delivery', it is designed to allow compatible devices to draw much more power from a USB 2.0 or USB 3.0 port – up to 100W. Partly this is achieved by the device negotiating for a higher supply voltage of either 12V or 20V, as well as beefier cables to carry up to 5A.

We haven't seen any devices which comply with this spec yet, but when they arrive, you'll have to be careful *NOT* to connect the *USB Power Monitor* between a port and device which may be operating at 12V or 20V. If you do and the bus voltage is increased, it will almost certainly destroy the *USB Power Monitor*.

Part of the spec involves having the hardware able to check that the attached cable(s) are capable of carrying the higher voltages and currents, so it's possible that they will refuse to deliver a higher voltage with the *USB Power Monitor* attached. But we wouldn't rely on it.

Parts list

- 1 double-sided PCB, available from the *EPE PCB Service*, coded 04109121, 65 × 36mm
- 1 4-digit LCD
- 1 PCB-mount right-angle USB Type A plug
- 1 PCB-mount right-angle USB Type A socket
- 1 5-pin header, 2.54mm pitch (CON3)
- 1 PCB-mount tactile pushbutton
- 1 80mm length of clear heatshrink tubing, 25-30mm diameter

Semiconductors

- 1 PIC18F45K80-I/PT programmed with 0410912A. hex (IC1)
- 1 INA282AID shunt monitor (IC2)
- 1 OPA2376AID dual op amp (IC3)

Capacitors (SMD 3216, X5R/X7R)

- 1 10 μ F 6.3V
- 3 220nF 16V

Resistors (SMD 3216, 1% 1/8W)

- 1 120k Ω
- 3 10k Ω
- 1 100 Ω
- 1 50m Ω 0.5% 0.5W 4-terminal shunt (element14 1462296)

Note: kits for this project are available from Jaycar Electronics with SMDs presoldered – Cat KC-5516).

measurements; otherwise, this resistance would effectively be in series with the resistor itself and thus its value would be higher than expected.

We measure the current flowing through the shunt by sensing the voltage drop across it. Ohm's Law tells us that this will be 50mV/A $\pm$ 0.5% (the resistor tolerance). So we will be measuring very small voltages; the unit will read down to 10 μ A or less, giving a voltage drop of around 0.5 μ V.

The voltage across the shunt is amplified by IC2, an INA282 chopper-stabilised 'zero-drift' current shunt monitor. This operates in a similar manner to an instrumentation amplifier, but is specifically designed for measuring current. It runs directly off the 5V USB supply from CON1, with a 220nF bypass capacitor to ensure low supply impedance.

As well as amplifying the voltage drop, it provides an output that is referenced to ground or some other low voltage, regardless of the supply voltage fed to the shunt which can be in the range of -14V to 80V. It can even measure current flow in either direction, but we are not using that feature in this circuit.

The INA282 has an internal 1:1 resistive divider between the REF1 and REF2 pins which can be used to generate a half-supply rail, so that the output can swing symmetrically for bidirectional current measurement. As we aren't using that feature, we simply tie the REF1 and REF2 pins together and drive them with a low-impedance voltage source which is then the reference (signal ground) voltage for IC2's output.

With no voltage across the shunt resistor, the output at pin 5 sits at the same voltage with which we are driving the REF1/REF2 pins (3/7). As the voltage across the shunt rises, the output voltage increases proportionally above this reference level. The INA282 has a fixed internal gain of 50, giving us an output of 2.5V/A.

IC2 can have an input offset voltage of up to $\pm$ 70 μ V and with a 50m Ω shunt, that gives an equivalent error of $\pm$ 1.4mA or $\pm$ 3.5mV at the output. This offset error varies from device to device but remains fairly constant over its life and with variations in supply voltage and temperature. The error is usually well under 3.5mV but can be enough to seriously affect low current readings (eg, in the microamp range) so we need a way to trim it out.

If that error was always positive, we could simply connect REF1 and REF2 to ground, have microcontroller IC1 (PIC18F45K80) measure IC2's output with no current flow, store that value and subtract it from future readings. But the offset voltage can be negative too and this scheme would fail to correct negative output errors.

To solve this, we are driving the REF1 and REF2 pins with a nominal 385mV reference level which is derived from the 5V supply using a resistive divider (120k Ω /10k Ω). This voltage is buffered by op amp IC3a, configured as a voltage follower. This ensures that REF1 and REF2 are driven with a low impedance, maintaining the accuracy of IC2's measurements.

The software in the micro measures the output of IC2 with no current

flowing, which is the $\sim$ 385mV reference plus IC2's output offset error. It can then subtract this from future readings and since the reference voltage is higher than the largest possible negative offset error, this will always be able to correct for the offset. It should not require frequent re-calibration as IC2 has a very low offset drift (hence its 'zero-drift' moniker).

Microamp measurements

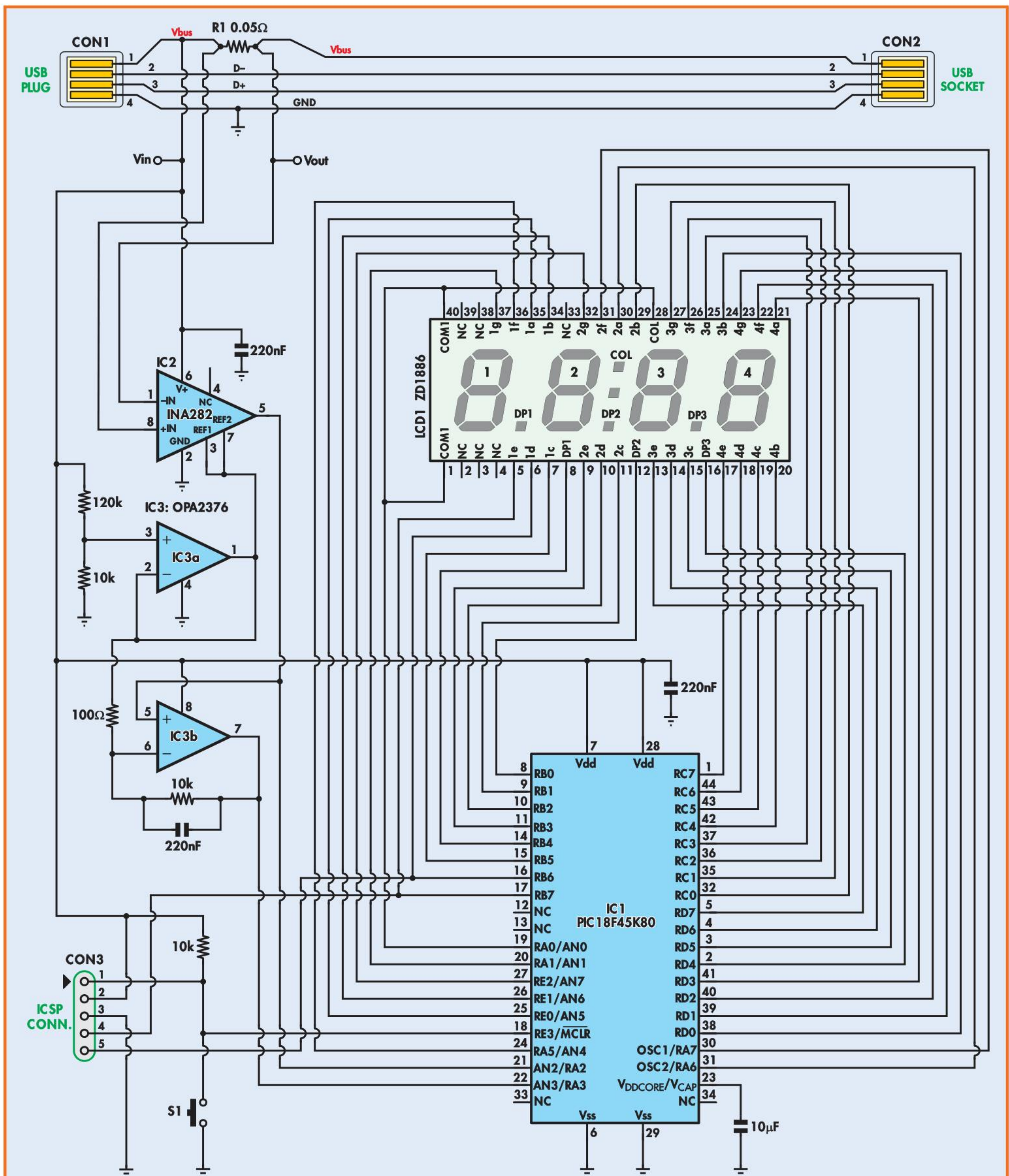
Op amp IC3b amplifies the output of IC2 by 100, to allow IC1 to accurately read low-current values. Unfortunately, this also amplifies IC2's offset error by a factor of 100. IC3b itself contributes a further offset of up to $\pm$ 2.5mV, but this pales in comparison to the up to $\pm$ 350mV error ($\pm$ 3.5mV $\times$ 100) contributed by IC2. This is why we chose a reference voltage of around 385mV, to allow for the full range of offset variations to be trimmed out.

The 220nF capacitor across IC3b's feedback resistor (10k Ω) greatly reduces the amount of noise from IC3b's output, as it dramatically reduces the gain stage's bandwidth to about 72Hz. IC3b's effective signal 'ground' is the same reference voltage that is fed to IC2.

Microcontroller IC1 measures the output of shunt monitor IC2 at its AN2 input (pin 21). Similarly, the amplified signal from IC3b goes to the AN3 input at pin 22. The micro can then select which voltage to measure. In practice, it does this by first measuring the voltage at AN3 and if this indicates a reading of 10mA or more, it measures AN2 instead for a greater measurement range.

We interpret readings from AN2 as 2.5mV/mA and for AN3, 250mV/mA. IC1 uses an internal 4.096V reference as the full-scale voltage for each conversion, giving a maximum reading of about 1.5A for input AN2 and 15mA for input AN3. With a 5V supply, the output of IC2 can go as high as 4.8V, giving us a maximum possible reading of about 1.75A.

As well as a very low offset voltage, op amp IC3 (OPA2376) has a number of other attributes which make it suitable for use in this type of application. It's designed to run from low supply voltages (2.7-5.5V) and has low noise, high bandwidth (5.5MHz), low quiescent current ($\sim$ 1.5mA) and an output that can swing to both supply rails (down to 0V and up to 5V).



USB POWER MONITOR

Fig.1: the complete circuit of the *USB Power Monitor*. USB current passes through a 50mΩ shunt resistor and the voltage drop across this is amplified by shunt monitor IC2 and then further amplified by op amp IC3b. Microcontroller IC1 uses its internal ADC to measure the current and display it on LCD1. Op amp IC3a buffers a reference voltage, used to allow IC1 to determine the static (offset) error in the current measurements.

Constructional Project

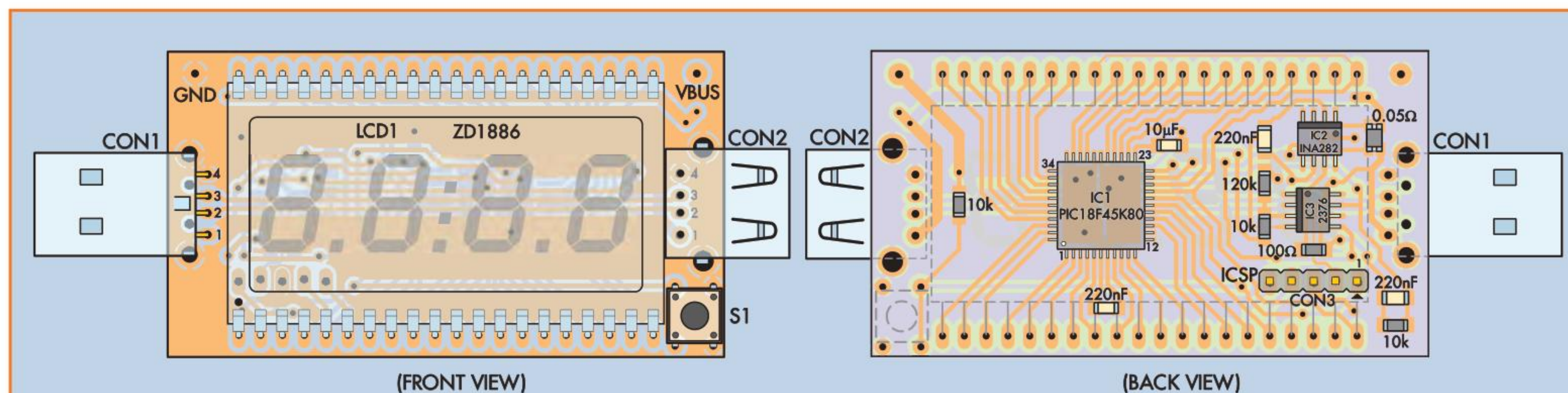


Fig.2: top and bottom views of the USB Power Monitor PCB. The LCD, connectors and pushbutton switch S1 (used to change modes) are the only components on the top. All the active circuitry goes on the underside and this keeps the unit compact. The VBUS and GND pads are provided so you can measure the USB voltage for calibration. The completed PCB assembly can be housed in clear heatshrink tubing for protection.

Note that the ~385mV reference voltage will vary with the USB supply voltage as it is derived from it. This could introduce an error in the current measurements but microcontroller IC1 can compensate for this by measuring the supply voltage and adjusting the value that it subtracts from each reading. This mostly eliminates the effect of supply variation on readings.

Note also that part of the reason for selecting a 50mΩ shunt is to keep its dissipation low over the expected current range. At 1A, it will dissipate just 50mW (I^2R) and even at 2A, it will be a manageable 200mW – the part is rated for up to 0.5W.

Display driving

The 4-digit LCD (LCD1) is driven directly by microcontroller IC1. The

LCD has a total of 32 segments – four 7-segment digits plus three decimal points (DP1-DP3) and a colon. Each segment is connected at one end to a dedicated pin while at the other end, all segments are joined together and connect to a pair of common pins, COM1 and COM2 at left. To turn a segment on (dark), we drive the segment with a 6-10V peak-to-peak square wave and to turn it off, we maintain 0V across the segment.

This is achieved by driving all the LCD pins (including COM1 and COM2) with one of two 5V 50Hz square waves which are 180° out of phase, ie, one is an inverted version of the other. Any segments driven with the same signal as the common pins have no voltage across them and so remain off. Those driven with the inverted square wave, compared to

the common pins, receive 10V peak-to-and so turn on.

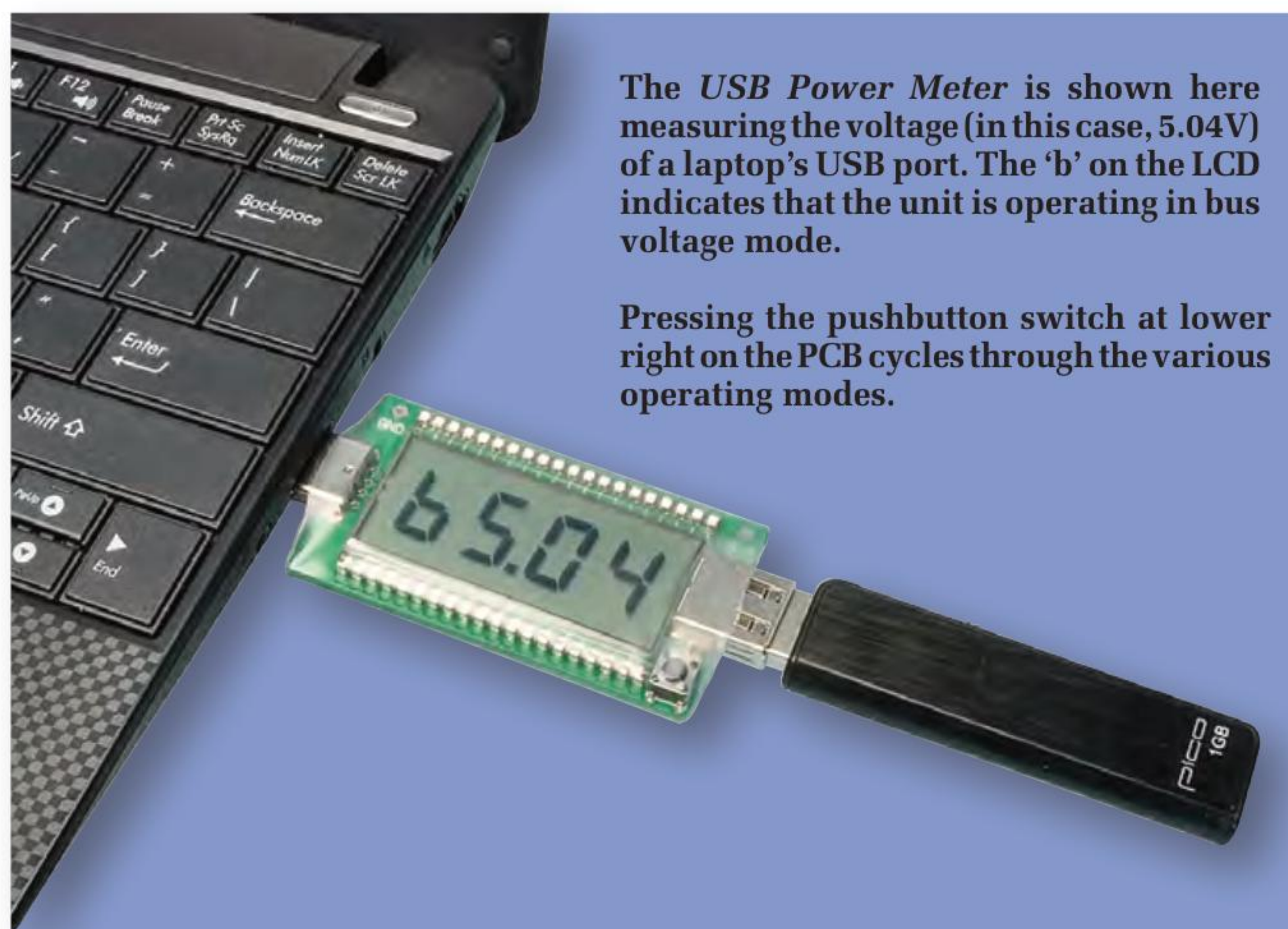
We use an AC drive signal since DC drive slowly damages the LCD by an electrochemical process. In this case, it's also required to provide a sufficient drive voltage as this method doubles the RMS voltage across the segments, ie, they receive 10V rather than 5V. The AC signals are generated using one of the microcontroller's internal timers and two of the compare units, combined with an interrupt handler routine that updates the output pins at 100Hz.

Like the analogue chips, microcontroller IC1 runs directly off the USB bus voltage. Note that we haven't made any additional connections from the USB supply to allow it to sense that voltage, in order to display it. Rather, this is achieved by configuring its ADC to sample its internal (nominal) 1.024V reference in relation to its supply voltage. It can then calculate the reciprocal of this in order to determine what its supply voltage and thus what the bus voltage actually is.

The same 1.024V reference is multiplied by four using an internal op amp, to produce the 4.096V ADC reference voltage which allows current measurements to be made accurately.

In addition to a 220nF bypass capacitor across the 5V supply, IC1 has a 10μF filter capacitor connected to its VDDCORE pin, which is required to allow its internal 2.5V core regulator to function properly.

A pushbutton is connected between pin 18 of IC1 (RE3/MCLR) and ground, with a 10kΩ pull-up resistor. Normally, this pin is used to reset the micro, but we have programmed it to disable that function so that we



The USB Power Meter is shown here measuring the voltage (in this case, 5.04V) of a laptop's USB port. The 'b' on the LCD indicates that the unit is operating in bus voltage mode.

Pressing the pushbutton switch at lower right on the PCB cycles through the various operating modes.



These views show the unit before the clear heatshrink tubing is fitted. Take care when soldering the SMDs – they must be correctly aligned with their pads. You can easily remove any solder bridges using solder wick. Note: prototype PCB shown; some resistor values changed for final version.

can use this pin as a digital input, to sense when the button is pressed. The button is used to change modes and also re-calibrate the unit.

The micro can still be programmed since the programmer pulls the MCLR pin well above 5V to activate programming. An in-circuit programming header (CON3) is provided although the header does not need to be soldered to the PCB and can be left out altogether if a pre-programmed chip is used.

Software

The software for IC1 is fairly simple but performs multiple tasks. It must constantly update all the LCD drive pins, sample the ADC inputs, perform calculations to determine what to display, monitor the pushbutton state and handle calibration tasks. It digitally averages the readings from each analogue input pin 2048 times to improve resolution and reduce noise.

When reading microamps or microwatts, some additional time averaging is performed on successive readings, if the readings are fairly steady, to prevent the bottom digit from jumping around due to circuit and power supply noise.

Input pin RE3 is monitored to check if S1 is pressed and if so, the display mode is changed. The current display mode is stored in EEPROM so that if you unplug and re-plug the unit, it retains its mode. This is

convenient but we also found that plugging certain USB devices in can cause the *USB Power Meter* to reset and since it powers back on in the same mode after a reset, the event is barely noticeable (besides a brief period with a blank or frozen display).

The software also contains calibration routines which measure the offset voltage and store it in EEPROM to adjust future measurements. During calibration, you can also correct for errors in the micro's internal 1.024V reference generator (specified as $\pm 7\%$ over the full temperature range). This offset is also stored in EEPROM and it is recommended that you trim this voltage as it also affects current readings, since the 4.096V ADC reference is derived from it.

The software compensates for power lost in the shunt when measuring the power drawn. This is necessary since the USB voltage measured is at the supply side rather than the load. This error is only significant for fairly high readings; eg, readings at 2.5W would be 0.5% high.

Construction

The components are all fitted on a PCB, available from the *EPE PCB Service*, coded 04109121 (65 × 36mm). The LCD module, USB connectors and pushbutton go on one side and everything else on the other.

Start by installing the surface-mount parts. It's best to begin with

the three ICs and then follow with the passive components. These are all fairly large for SMDs so you should not encounter too many difficulties.

Start by applying some solder to one of the IC pads and then, using tweezers, slide the part into place while heating the solder on that pad. Remove the iron and check that the part is correctly oriented (pin 1 dot/divot as shown) and that it is properly centred on its pads. If not, re-heat the solder and gently nudge the chip into place. Repeat until it's right and then solder the rest of the pins. Remember to re-fresh the solder on the first pin you soldered when you're finished.

If you accidentally bridge any of the pins, simply use solder wick to clean it up. A dab of no-clean flux paste applied to the bridge beforehand makes it disappear a lot more quickly and easily.

The same basic technique applies for the passive parts, although they only have two pads so it's generally much easier and alignment is less critical. The exception is the 50mΩ shunt resistor which has four (small) pads, but as long as you line it up correctly and don't use an excessive amount of solder, it should all go smoothly.

Check the shunt resistor carefully with a magnifying glass after you have soldered it, to ensure that the closely-spaced pairs of pads at each end have not been bridged. If they have, use flux paste and solder wick to remove the excess solder.

With all the SMDs in place, flip the PCB over and fit the LCD. First you must bend the pins straight; they are kinked but will not fit through the holes in the PCB until you straighten them. This is easily done with small, straight pliers, one pin at a time. When you're finished, they should leave the LCD module at right-angles and have no kinks.

You can then fit the LCD module into place but be sure to install it the right way around. To do this, first hold the module at an angle to the light so that you can see where the decimal points are – these go towards the bottom of the PCB.

The straightened pins can be tricky to line up with the holes in the PCB so you will probably have to feed them through one at a time. Once you have them all in, push the module down so that it sits flat against the PCB and then solder all the pins.

Constructional Project

You can then finish up by installing the USB plug and socket and the pushbutton switch. In each case, these should be pushed down fully onto the board before being soldered. For the USB plug and socket, solder the large mounting pins first and then the four signal pins. The plug goes on the left and the socket on the right. There won't be much of a gap between the LCD and the socket but it should fit.

Testing and calibration

To test the unit, you simply plug it into a USB port. You should immediately see a display on the screen which will read 'C5.00' or similar, with the number indicating the sensed USB supply voltage. The decimal point should also be flashing. This indicates that the unit is in calibration mode.

If you don't get such a display, unplug it and check for faults such as bad solder joints or bridged pads.

Assuming it's OK, set your DMM to DC volts and measure the voltage between the 'VBUS' and 'GND' points on the PCB (top corners). You should get a reading pretty close to that shown on the unit, but it may be slightly off.

If it's off, press pushbutton S1 briefly and release it. Shortly afterwards, you should see the reading on the display change slightly. Continue pressing S1, with a pause after each press to check the new reading, until the unit shows the same voltage as your multimeter, to within 10mV. You may need to re-check the DMM reading in case the USB voltage has changed slightly as you approach the correct reading.

Once the display is correct, press and hold pushbutton S1 for several seconds until the display shows 'CALI' and then release it. After a couple of seconds, calibration will be complete and the unit will display the measured current in milliamperes, which should be very close to zero.

Now plug in a USB device (eg, a hub) and check that the reading increases. You can then press the switch to cycle through the current, voltage and power modes (see below) and check that each reading is approximately correct.

Once you are happy that the unit is working and correctly calibrated, you can then trim the heatshrink tubing so that it is about 10mm longer than the PCB, slip it over the unit and apply some gentle heat (from a heat gun on

low or a hairdryer) to shrink it. Trim away any excess tubing that protrudes past the ends of the PCB.

You can still access the V_{BUS} and GND terminals to re-calibrate it later, if that becomes necessary, through the ends of the tubing. It may then be more convenient to use the USB plug shell as your ground reference point.

Display

During normal operation, there are three modes: current, voltage and power. Pressing S1 briefly cycles through these modes.

In current mode, there are three ranges and the unit switches automatically. Typically, it will read either 'x.xxx' or 'xxx.x' where x is a digit from 0 to 9. These readings are in milliamperes and the lower range (with microamp resolution) is automatically selected for readings below 10mA. For 1A and above, the display changes to 'x.xx A'.

In voltage mode, the read-out is always in the format 'bx.xx' where x.xx will be a number usually between 4.40 and 5.50. 'b' is short for 'bus voltage' (it's not possible to do a V with a 7-segment display).

In power mode, there are three possible ranges and again it is auto-ranging. For readings of 10mW and above, you will get a read-out in watts of either 'Px.xx' or 'P.xxx', both in watts. Below 10mW, the display will change to 'Lx.xx', with the reading in milliwatts. The 'L' stands for 'low power'.

To re-enter calibration, hold down S1 for several seconds. You can then go through the steps above to recalibrate the unit.

Flip mode

If you plug the unit into a left-side USB port, the reading will be upside-down. This can be fixed by holding down S1 while plugging it in, which enables flip mode. The decimal points are now at the top of the display but the digits will be shown the right way up and you can read it as normal. To disable flip mode, you again hold down S1 while plugging the unit in. Otherwise, it will stay in flip mode.

That's it. Now you will no longer be in the dark about the power your USB devices consume.

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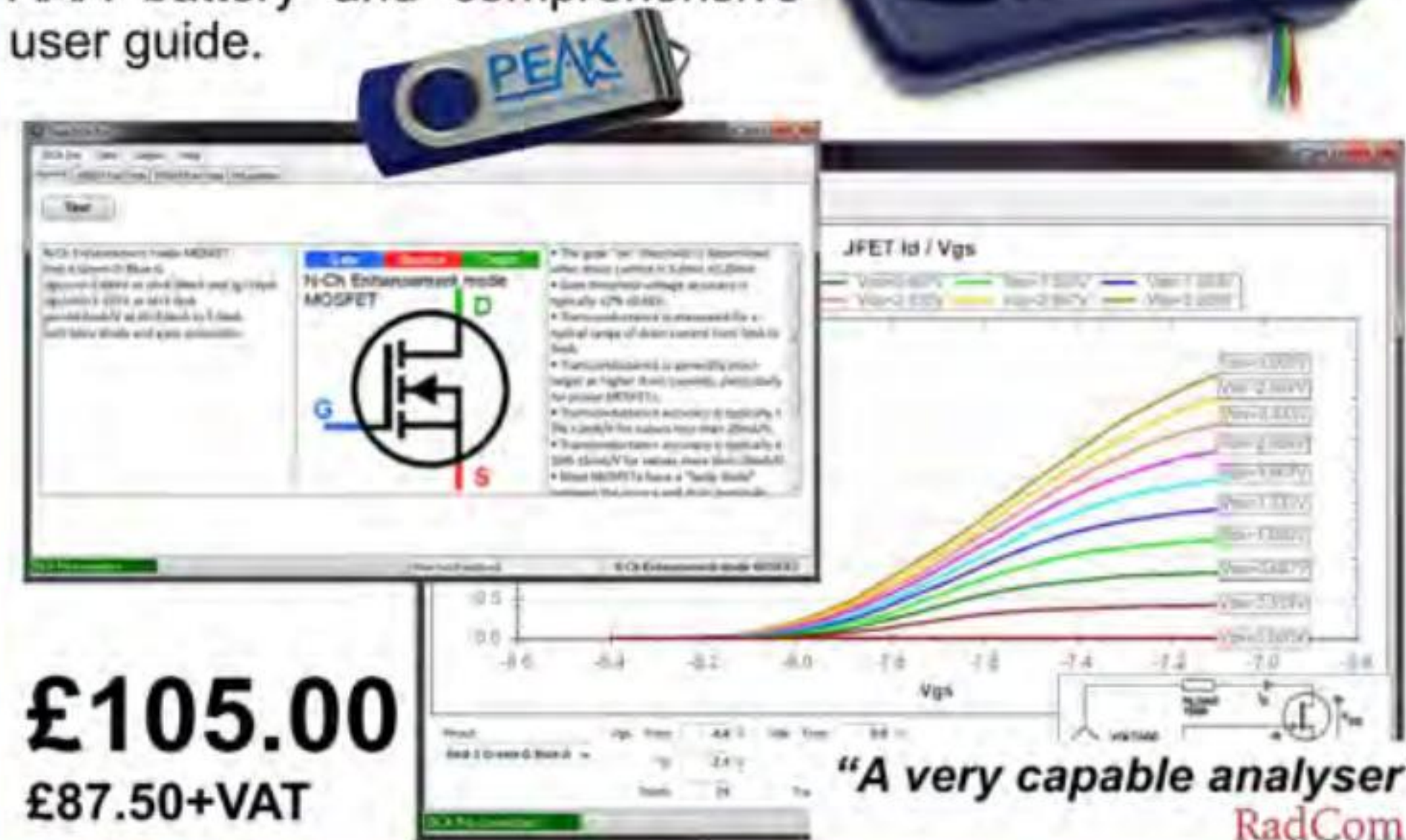
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Teach-In 2016

Exploring the Arduino

Part 7: Arduino Nano

by Mike and Richard Tooley



Welcome to *Teach-In 2016 – Exploring the Arduino*. This exciting new series has been designed for electronics enthusiasts wanting to get to grips with the immensely popular Arduino microcontroller, as well as coding enthusiasts who want to explore hardware and interfacing. So, whether you are considering what to do with your Arduino, or maybe have an idea for a project but don't know how to turn it into reality, our new *Teach-In 2016* series will provide you with a one-stop source of ideas and practical information.

In last month's *Teach-In 2016 Exploring the Arduino* we looked at ways in which an Arduino can communicate with remote devices using low-cost wireless modules. *Arduino Workshop* introduced wireless modules while *Arduino World* looked at short-range wireless systems that can be used to send data from one Arduino to another. Our programming feature, *Coding Quickstart*, introduced the RadioHead Packet Radio library for embedded microprocessors, while our *Get Real* project put this all into practice with a simple wireless-linked rain alarm.

This month

In *Arduino World* we will look at the Arduino Uno's diminutive cousin, the Arduino Nano. This tiny microcontroller provides you with a highly cost-effective alternative to the Uno that's small enough to be tucked away into an extremely small space. *Arduino Workshop* will introduce you to passive infra-red (PIR) motion sensors, and our programming feature, *Coding Quickstart*, will look at tone generation. Finally, our *Get Real* project describes the design and construction of an Arduino Nano-based PIR motion alarm.

Arduino World: the Nano

Thus far in our series we have used the popular Arduino Uno simply because it makes an excellent low-cost, entry-level microcontroller. However, for some applications the Uno is not the best solution and, particularly where space is at a premium, the tiny Arduino Nano can be a better choice and at even lower cost (currently around £3).

The latest version of the Nano uses the same ATmega328 processor as the Uno R3 (see *EPE*, February 2016) while earlier versions (2.x) were based on the less powerful ATmega168. The four-layer microcontroller board offers similar functionality to the Uno but in a much smaller package and without the ability to accommodate standard Uno shields and expansion modules. The Nano dispenses with the bulky DC power connector fitted to the Uno and instead it derives

its power via a Mini-B USB cable that is also used for downloading code. One feature of particular note is that not only does the Nano have diminutive

DC supply

The Arduino Nano can be powered via the Mini-B USB connector but for most stand-alone applications we recommend a supply of between 7V and 12V derived from an external power source (eg, 9V PP3 battery). This should be connected via pin-30 (VIN) and pin-29 (GND). Alternatively, a 5V regulated external power supply can be connected to pin-27 and pin-29 (GND). To keep things simple, the board's power source is automatically selected to the highest voltage source. Depending on the I/O load, a Nano requires a typical supply current in the range 20mA to 120mA.

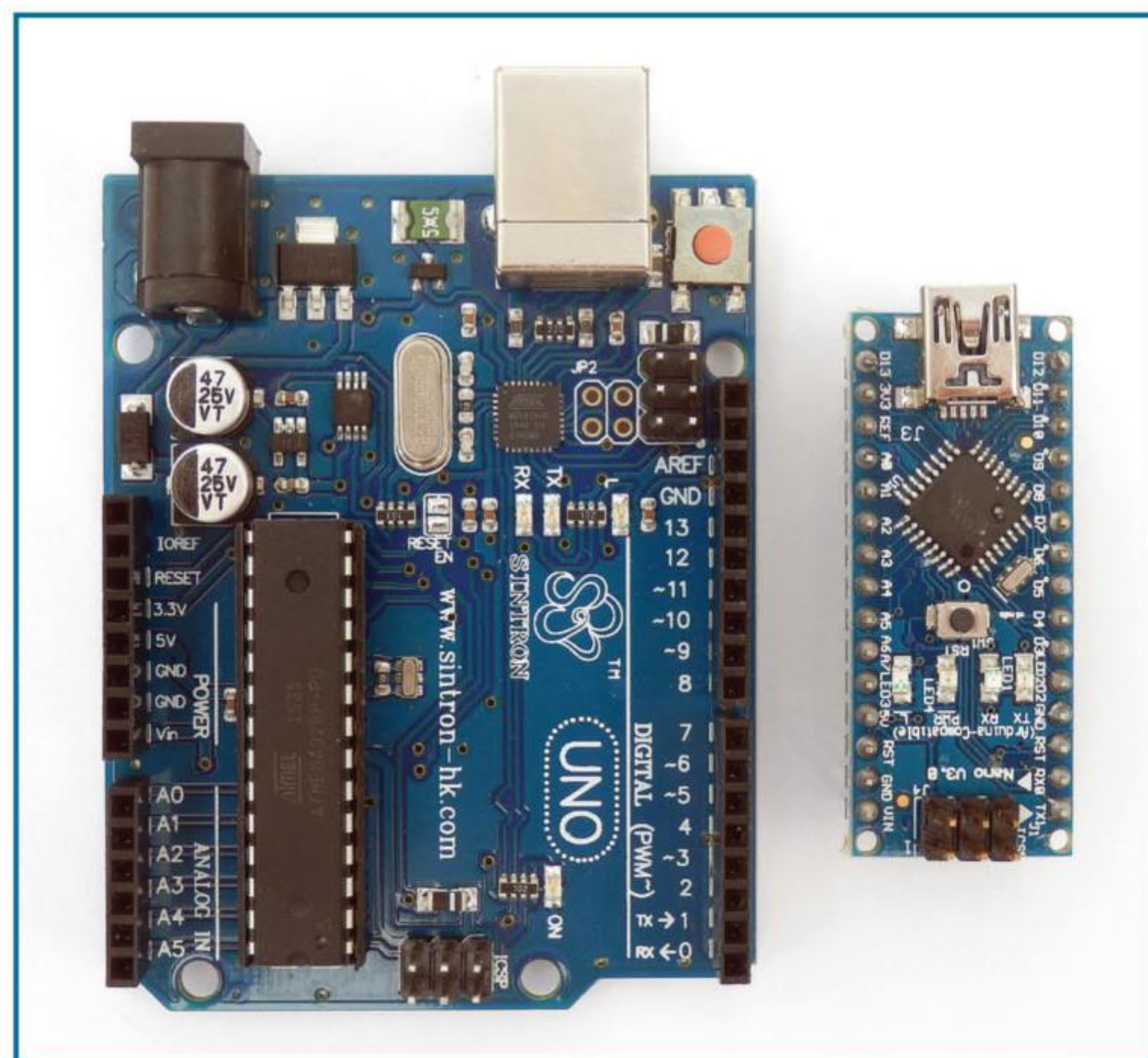


Fig.7.1. The Arduino Uno and its diminutive cousin the Arduino Nano

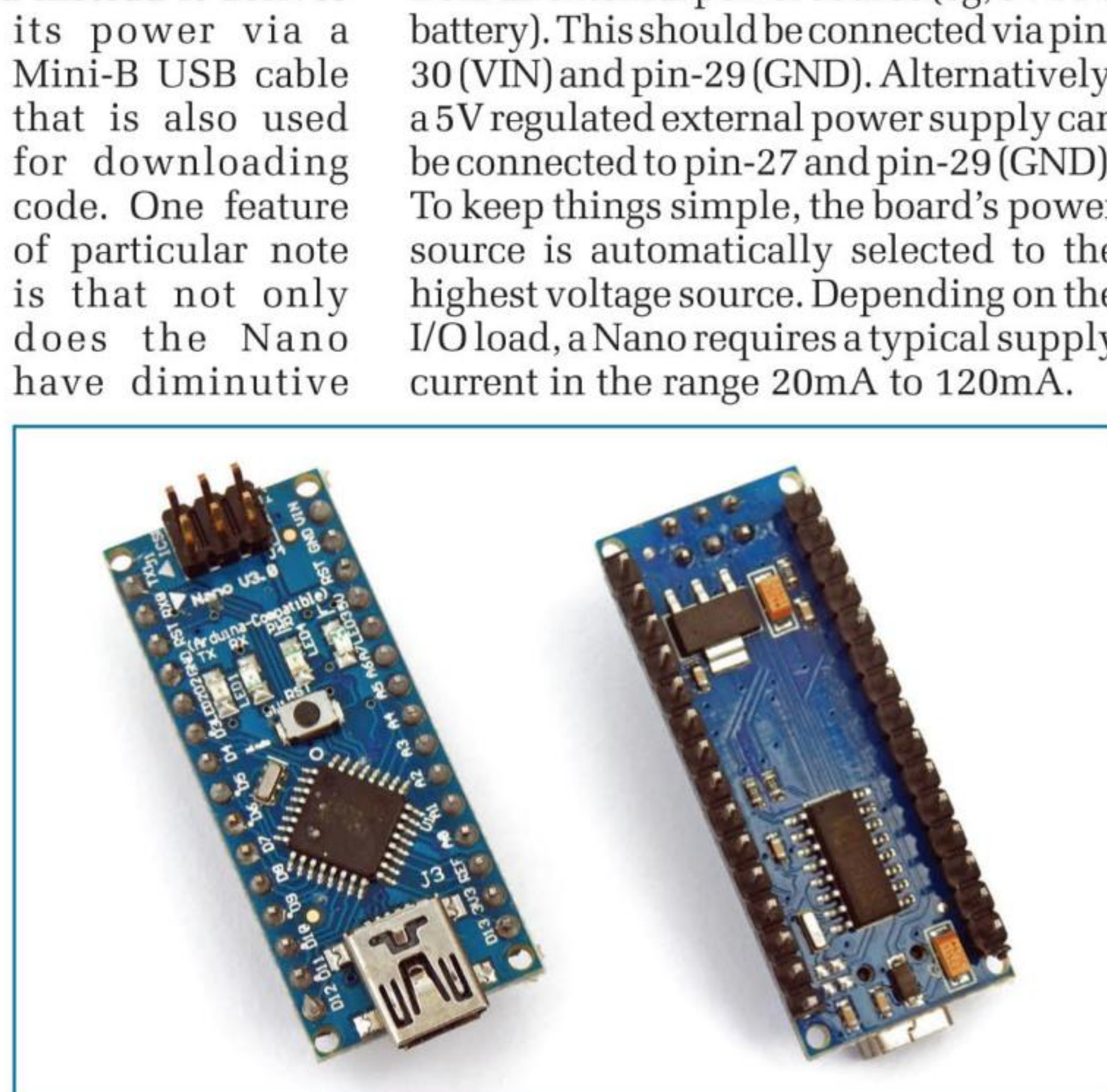


Fig.7.2. Front and rear views of the Nano's four-layer PCB

Technical specifications for the Arduino Nano 3.x

Feature	Specification
Microcontroller	ATmega328P
Clock speed	16MHz
Flash memory	32kB (note 1)
Static RAM (SRAM)	2kB
EEPROM	1kB
Supply voltage	5V
Recommended DC input voltage range	7V to 12V (note 2)
Digital I/O pins	14
Digital I/O pins available for PWM output	6 (note 3)
Analogue input pins	8
Max. DC current output per pin	40mA
Max. DC current available from 3.3V supply	50mA
Dimensions	45mm × 18mm
Weight	5g

Notes

- 1. 2KB of which is used for the bootloader
- 2. Maximum DC input voltage is 20V
- 3. See Table 7.1

Memory

The ATmega168 processor has 16KB of Flash memory for storing code (of which 2KB is used for the bootloader) whilst the ATmega328 offers 32KB (also with 2KB occupied by the bootloader code). The original Nano with its ATmega168 provides 1KB of SRAM and 512 bytes of EEPROM (which can be read and written with the EEPROM library). The Nano 3.x with its ATmega328 has 2KB of SRAM and 1KB of EEPROM.

Digital I/O

The Nano provides 14 digital I/O pins and each of them can be configured for use as an input or output. The digital I/O pins operate at standard 5V logic levels and each pin can source or sink a maximum of 40mA. An internal pull-up resistor (of 20-50kΩ) is available. By default, the pull-up resistors are disconnected. The I/O pins are configured and

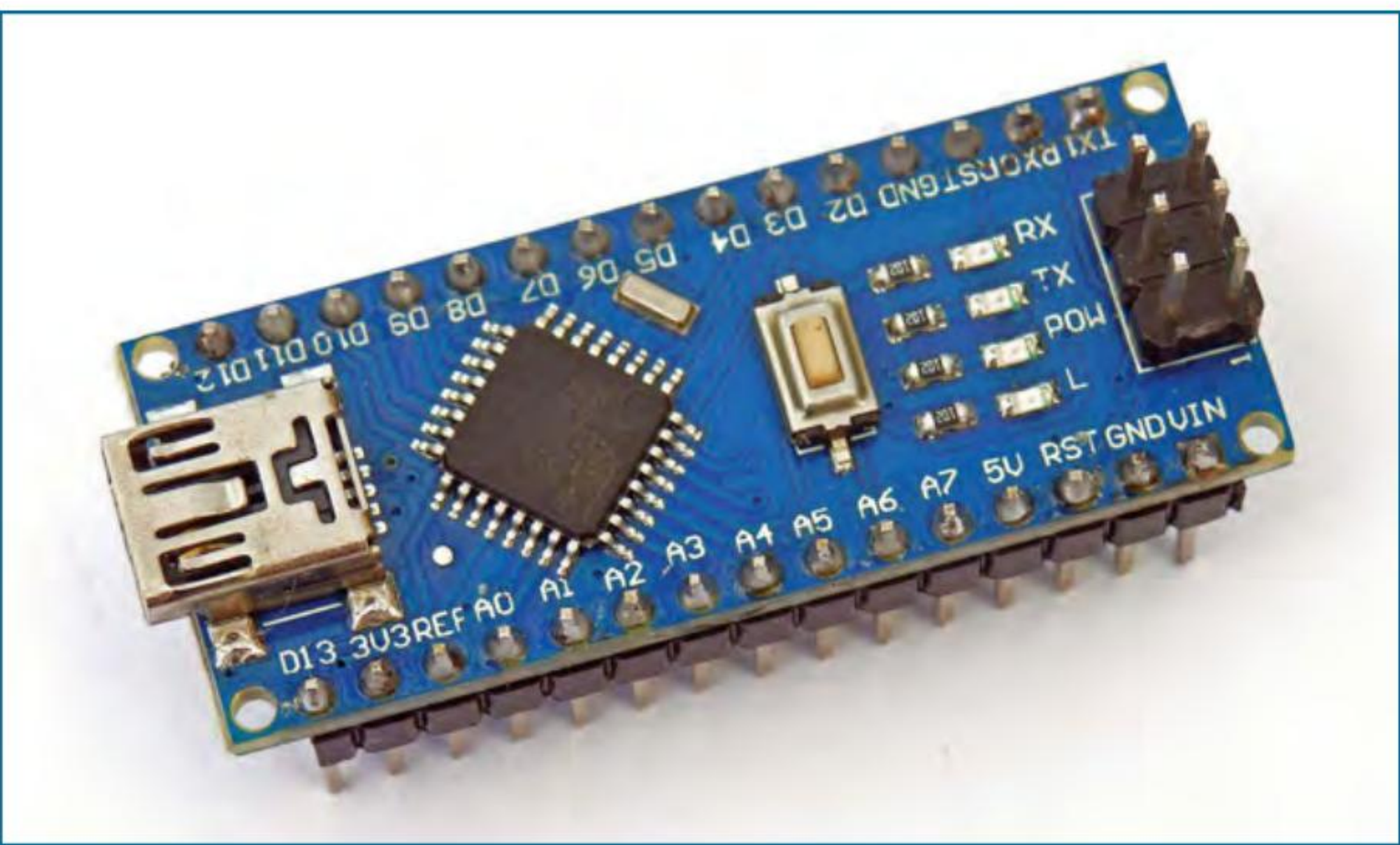


Fig.7.3. Nano pin connections are grouped on opposite sides of the PCB

treated in exactly the same way as the Uno by means of `pinMode()`, `digitalWrite()`, and `digitalRead()` functions. Note that, as with the Uno, several of the digital I/O pins also have special functions as listed in Table 7.1. We will be looking at pulse-width modulation (PWM), and how this can produce an analogue output voltage, in a future *Teach-In 2016*.

Analogue inputs

The Nano caters for up to eight analogue inputs and each offers a resolution of 10 bits (the same as the Uno). The input voltage range, by default, is 0V to +5V, but this can be changed by altering the analogue reference voltage in the same way as this can be changed for the Uno. Note also that analogue pins 6 and 7 cannot be used as digital pins. As with the digital I/O, some pins have special functions, as listed in Table 7.2.

Communication facilities

The Arduino Nano has a number of facilities for communicating with the outside world using standard UART TTL-level serial communication available on digital I/O 0 on pin-1 and digital I/O 1 pin-2. An on-board FTDI FT232RL chip channels this

Table 7.1 Special I/O functions associated with digital I/O

Digital I/O	Board pin number(s)	Signal/designation	Special function
D0 and D1	1 and 2	Serial 0 (RX) and Serial 1 (TX)	Used to receive (RX) and transmit (TX) TTL serial data. These pins are connected to the corresponding pins of the FTDI USB-to-TTL serial chip
D2 and D3	5 and 6	External interrupts	These pins can be configured to trigger an interrupt on a low value, a rising or falling edge, or a change in value
D3, D5, D6, D9, D10, and D11	6, 8, 9, 12, 13 and 14	Pulse width modulation (PWM)	These pins can be used to generate 8-bit PWM outputs
D10, D11, D12 and D13	13, 14, 15 and 16	Serial peripheral interface (SPI)	These pins provide access to the SS (D10), MOSI (D11), MISO (D12) and SCLK (D13) SPI signals
D13	16	LED indicator (L)	Built-in LED indicator (when the pin is taken HIGH the LED will be illuminated, and vice versa)

Note: it is important to avoid confusing the Digital I/O numbers with the board pin numbers – they are not the same but they are very easily confused!

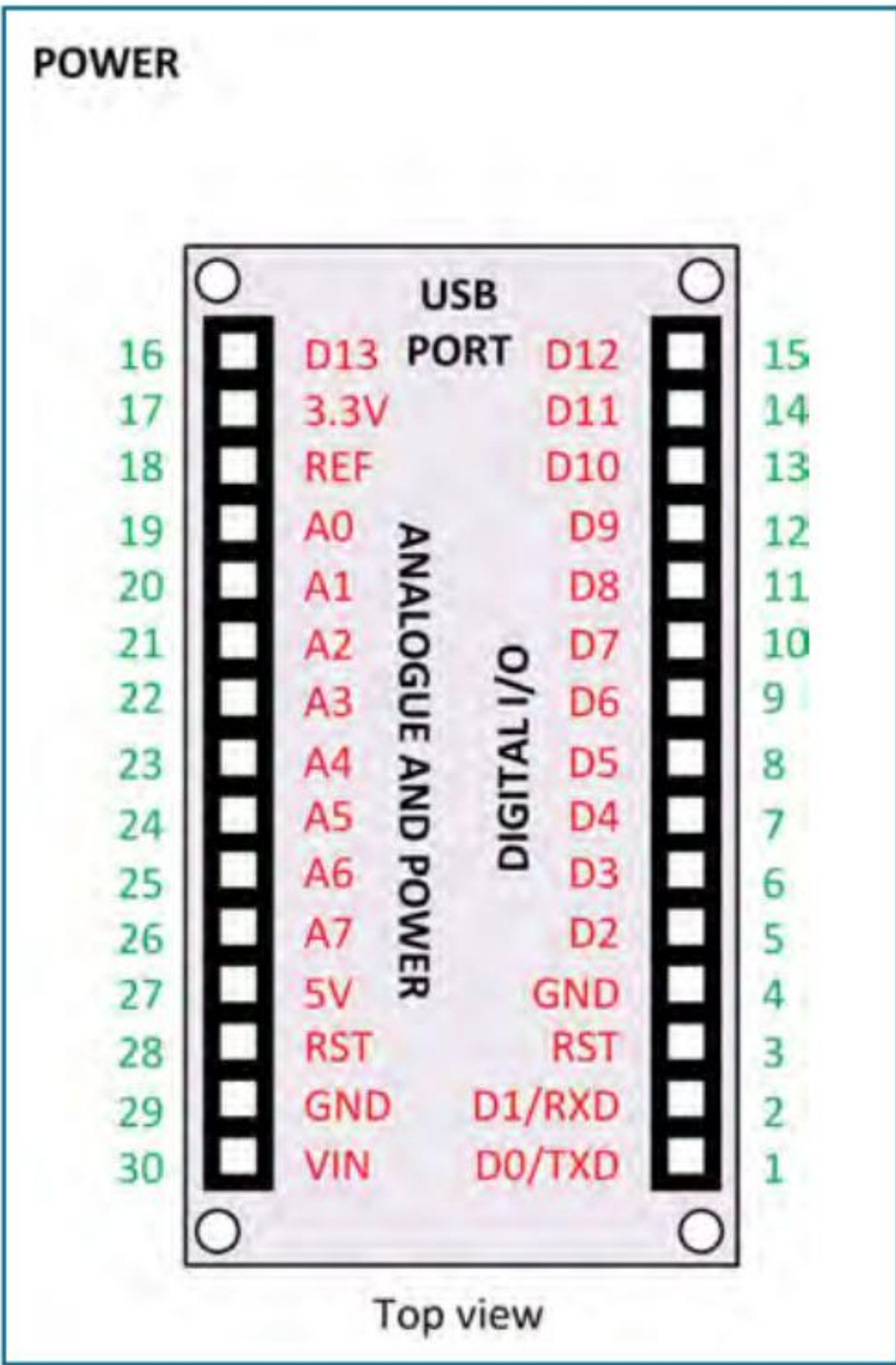


Fig.7.4. Nano pin connections (for clarity we have shown the signal designations in red and the pin numbers in green)

serial communication over USB, and the FTDI drivers (included with the Arduino software) provide a virtual COM port on the host computer. The IDE's Serial Monitor allows basic text to be sent to and from the Arduino board using the serial interface. As a helpful indicator, the RX and TX LEDs on the board will flash when data is being transmitted via either the FTDI chip or the USB port. Note that these LEDs will *not* operate when TTL-level serial communication is being used via digital I/O pins 0 and 1.

The Nano's Software Serial library also permits serial communication on any of the Nano's digital I/O pins. As with the Uno,

Table 7.2 Special I/O functions associated with analogue I/O

Analogue I/O	Board pin number(s)	Signal/designation	Special function
A4 and A5	18 and 19	I ² C (two-wire interface)	A4 is SDA and A5 is SCLK
VREF	18	Analogue reference voltage	Used to change the DAC range of analogue inputs
RST	28	Reset input	Take LOW to reset microcontroller (often used when a shield obstructs the board's own reset button)

the Nano supports I²C (TWI) and SPI communication. If you intend to make use of these features you will need to include the necessary library files in your code, as described earlier in this series.

Programming

The Arduino Nano can be programmed in exactly the same way as described previously for the Uno. The microcontroller will be immediately recognised when selected from the board options within the standard Arduino IDE. As with the Uno, the ATmega processors are supplied with a pre-loaded bootloader that allows you to upload new code without the use of an external hardware programmer. However, if the need arises, it is possible to bypass the bootloader code and program the microcontroller through in-circuit serial programming (ICSP). Note that you won't actually need to do this for any of our *Teach-In 2016* projects

LED status indicators

The Nano has four miniature surface-mounted LED status indicators, as shown in Fig.7.5. Two of these (marked 'TX' and 'RX') show the status of the two serial communication lines, while another provides power indication and the fourth led (marked 'L') is driven from digital I/O pin-13 and is available for general use.

Reset

The Nano has a reset button that is located in the centre of the board, as shown in Fig.7.5. Pressing this button restarts the resident code. Note that, rather than requiring a physical press

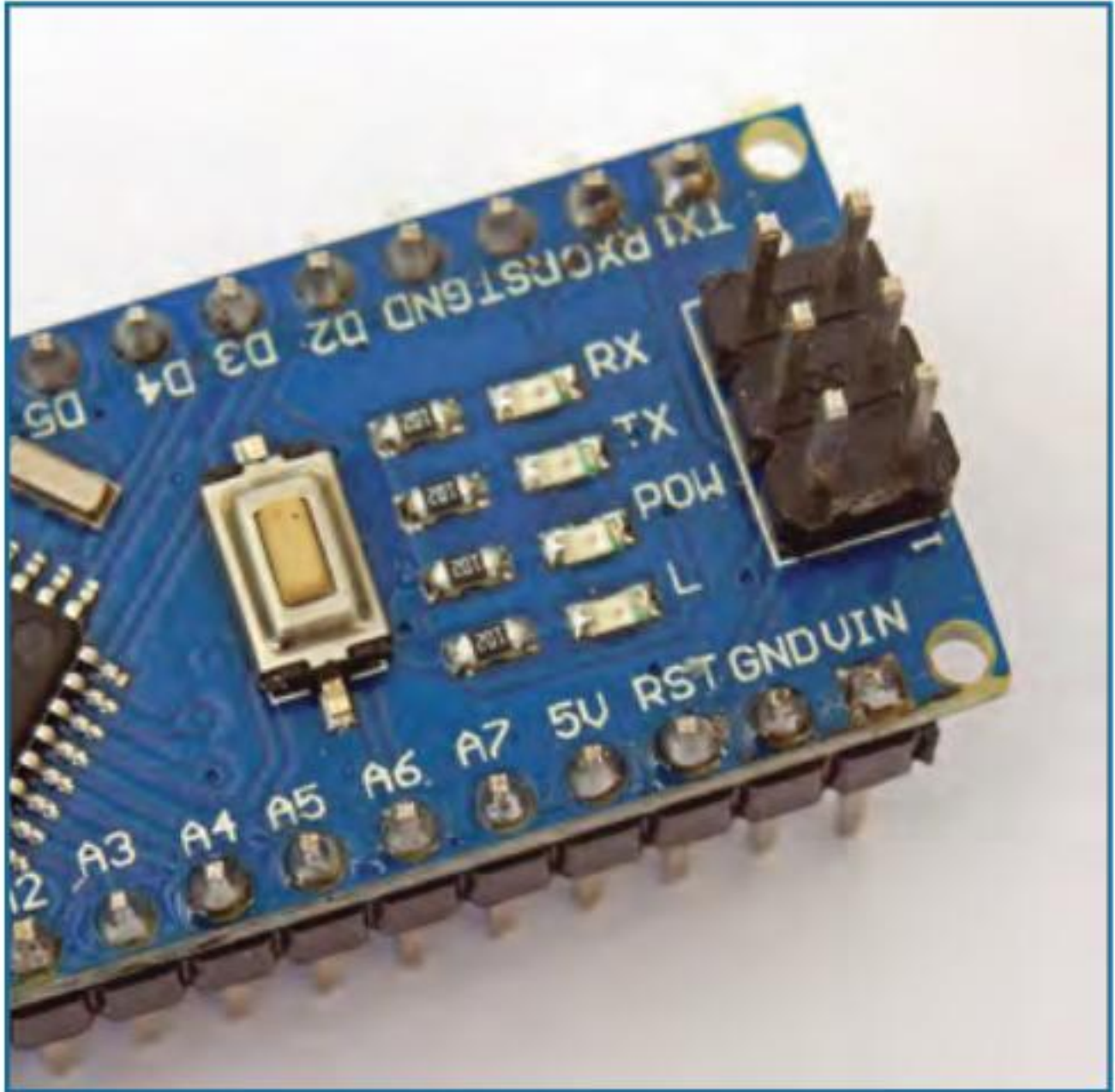


Fig.7.5. The Nano's four LED status indicators

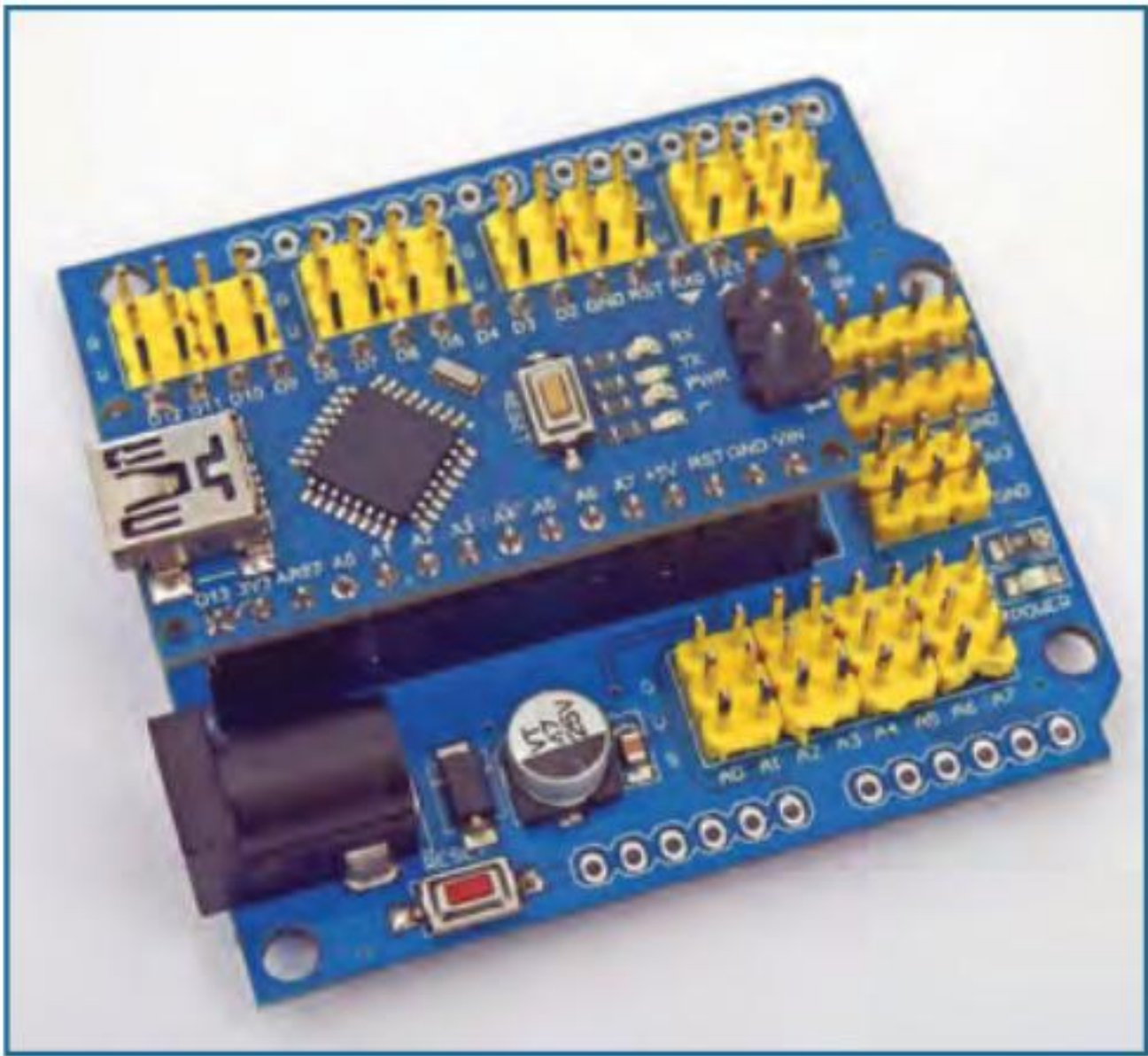


Fig.7.6. Deek Robot prototyping board with Arduino Nano mounted

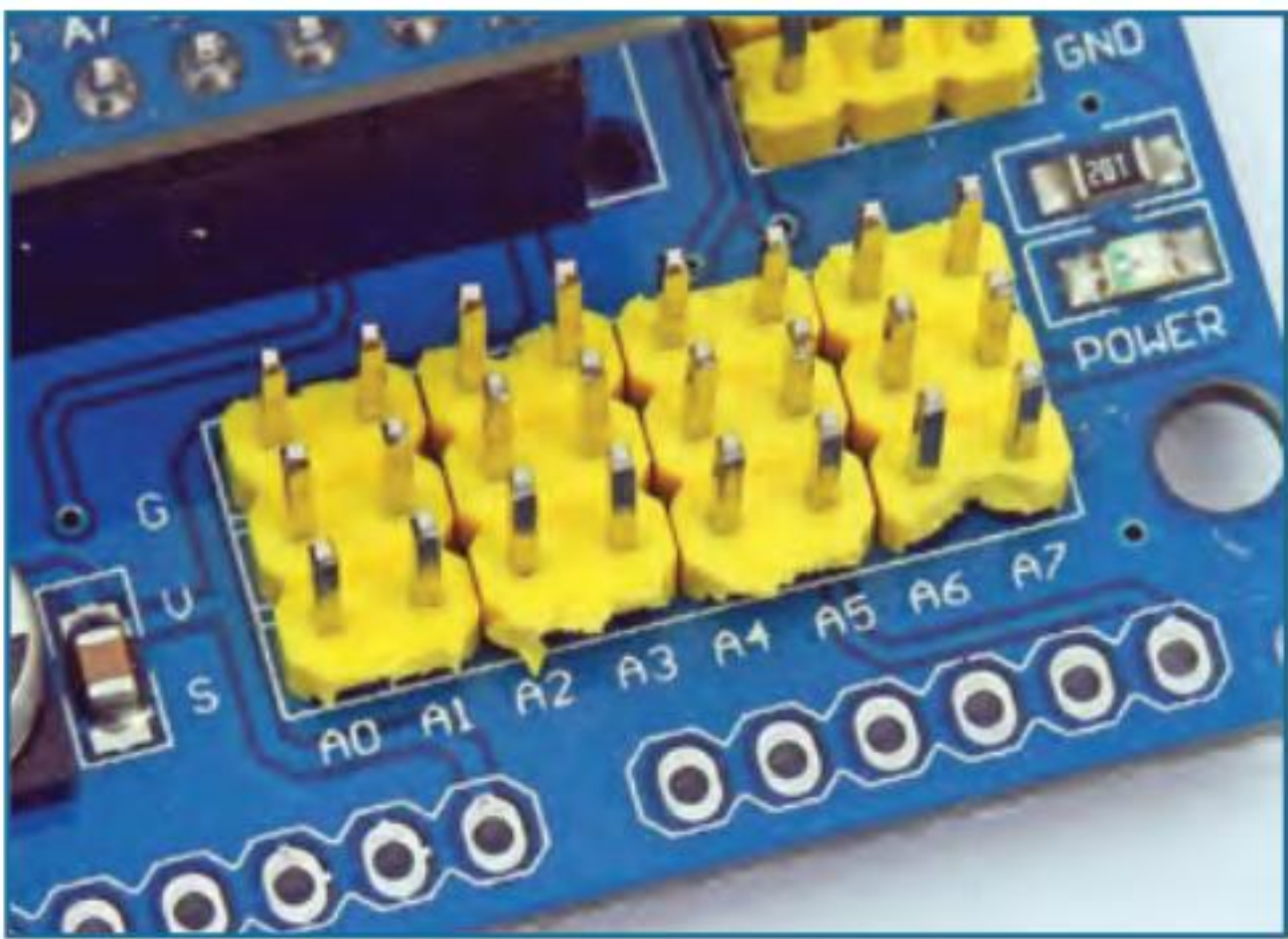


Fig.7.7. Deek Robot prototyping board groups signal inputs together with individual connections to the positive supply and ground

of the reset button before an upload, the Arduino Nano is designed in a way that allows it to be reset by software running on a connected computer. One of the hardware flow control lines (DTR) of the serial interface chip (an FT232RL) is connected to the reset line of the ATmega processor via a 100nF capacitor. When this line is taken low, the reset line drops for just long enough to reset the chip. The Arduino software uses this capability to allow you to upload code by simply pressing the upload button in the Arduino environment.

Prototyping with the Nano

Due to its small size and the two rows of male pins (rather than the female headers connected to the Uno) it can sometimes be a little difficult to prototype circuits with a Nano. One solution is to simply plug the Nano into a breadboard of suitable size, but undoubtedly the best and most reliable solution is using a low-cost prototyping board like that supplied by Deek Robot, as shown in Fig.7.6. A handy advantage of the Deek Robot prototyping board is that signal connections (marked 'S') have been grouped together with power (marked 'V') and ground (marked 'G') connections (see Fig.7.7). This makes it extremely easy to place required logic levels on the I/O pins without a great deal of messy wiring. Another useful feature is that you will not need to refer to pin numbers. Or you can just use the signal designations printed on the off-board headers. By now you can probably guess that we are fans of this particular board!

Arduino Workshop: Passive infra-red motion sensing

In conjunction with some form of alarm or lighting system, PIR motion sensing is an excellent application for a microcontroller such as the Uno or Nano. To simplify matters, low-cost PIR sensors are widely available and they require minimal interfacing (just a power supply and a digital input on the microcontroller). Depending on positioning (see Fig.7.8) a typical PIR motion sensor will be sufficient for a room size of about 14m². This is ample for most domestic situations as well as smaller commercial properties.

The PIR detection range depends on a number of factors, including the size and speed of the target object and its angular position relative to the sensor. It

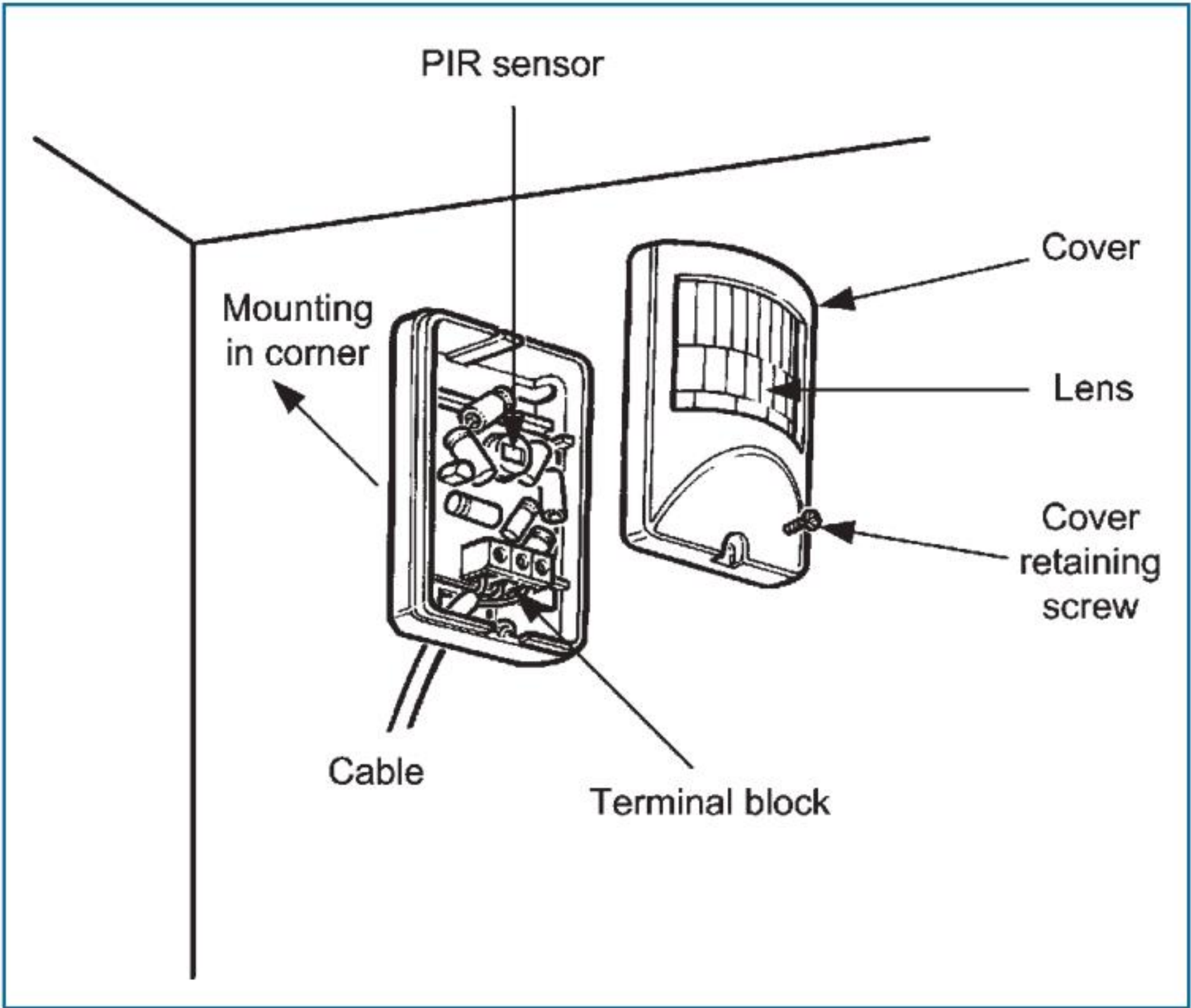


Fig.7.8. Typical commercially available PIR motion sensor mounted in the corner of a room

Listing 7.1 PIR test routine

```

/* PIR test routine */

// Input and output
int inputPIR = 2;    // Input from PIR sensor
int outputLED = 13;  // Output to LED indicator

void setup() {
  pinMode(outputLED, OUTPUT);
  pinMode(inputPIR, INPUT);
}

void loop() {
  digitalWrite(outputLED, digitalRead(inputPIR));
}

```



Fig.7.9. Low-cost PIR module with lens removed revealing the PIR sensor

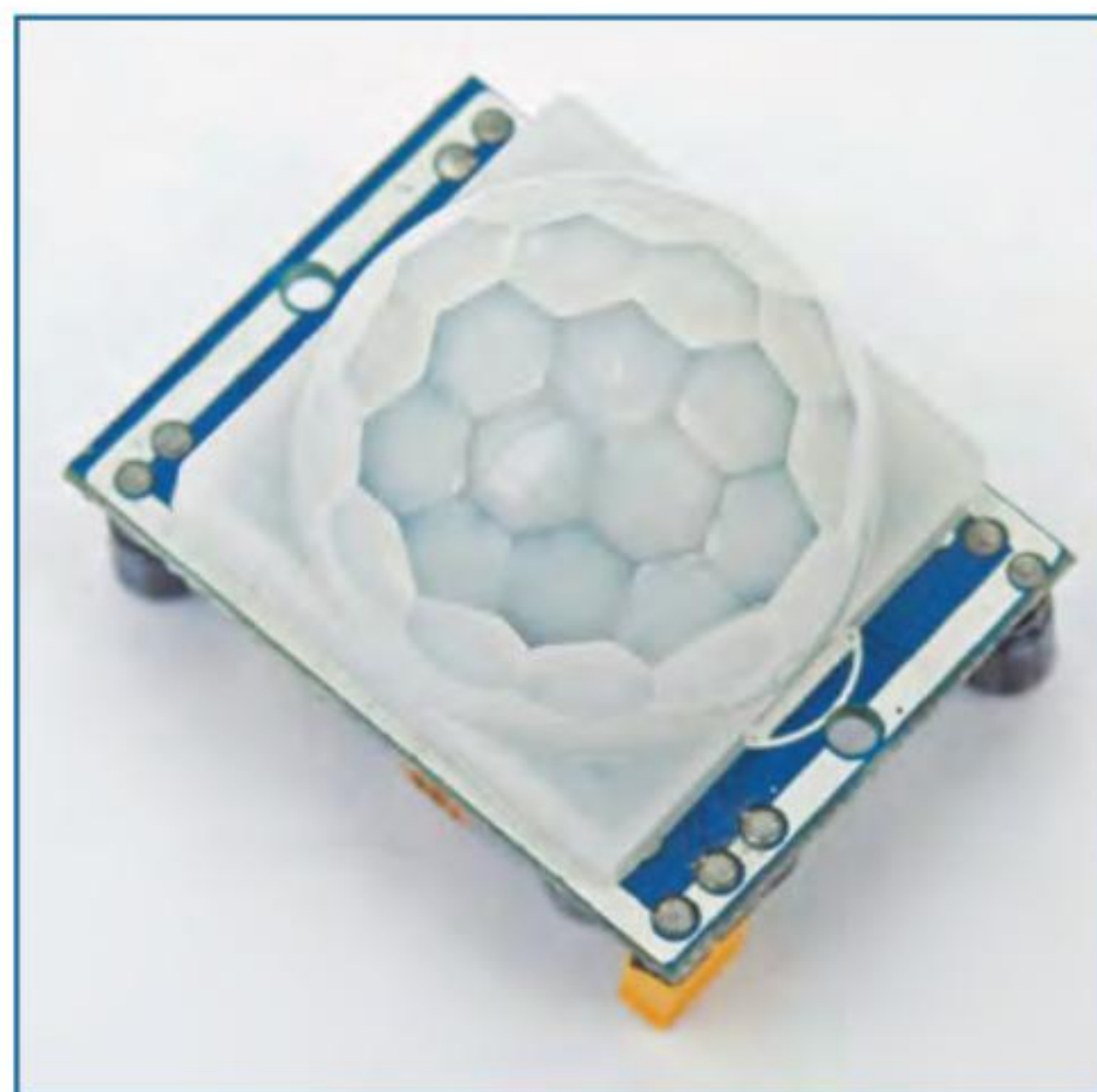


Fig.7.10. Low-cost PIR module with lens cover fitted

is therefore a little difficult to predict the exact range of any particular installation.

A typical low-cost PIR module is shown (with the PIR sensor chip exposed) in Fig.7.9. In use, the sensor is covered with a lens (see Fig.7.10). This not only helps to increase the angular response, but also divides the coverage into sectors through which a target moves. The sensor module can be connected to an Arduino using one of the digital I/O pins (plus ground and +5V) as shown in Fig.7.11. In this arrangement we have used a digital I/O pin (which is also the 'L' LED pin) which will need to be configured as an input in our code.

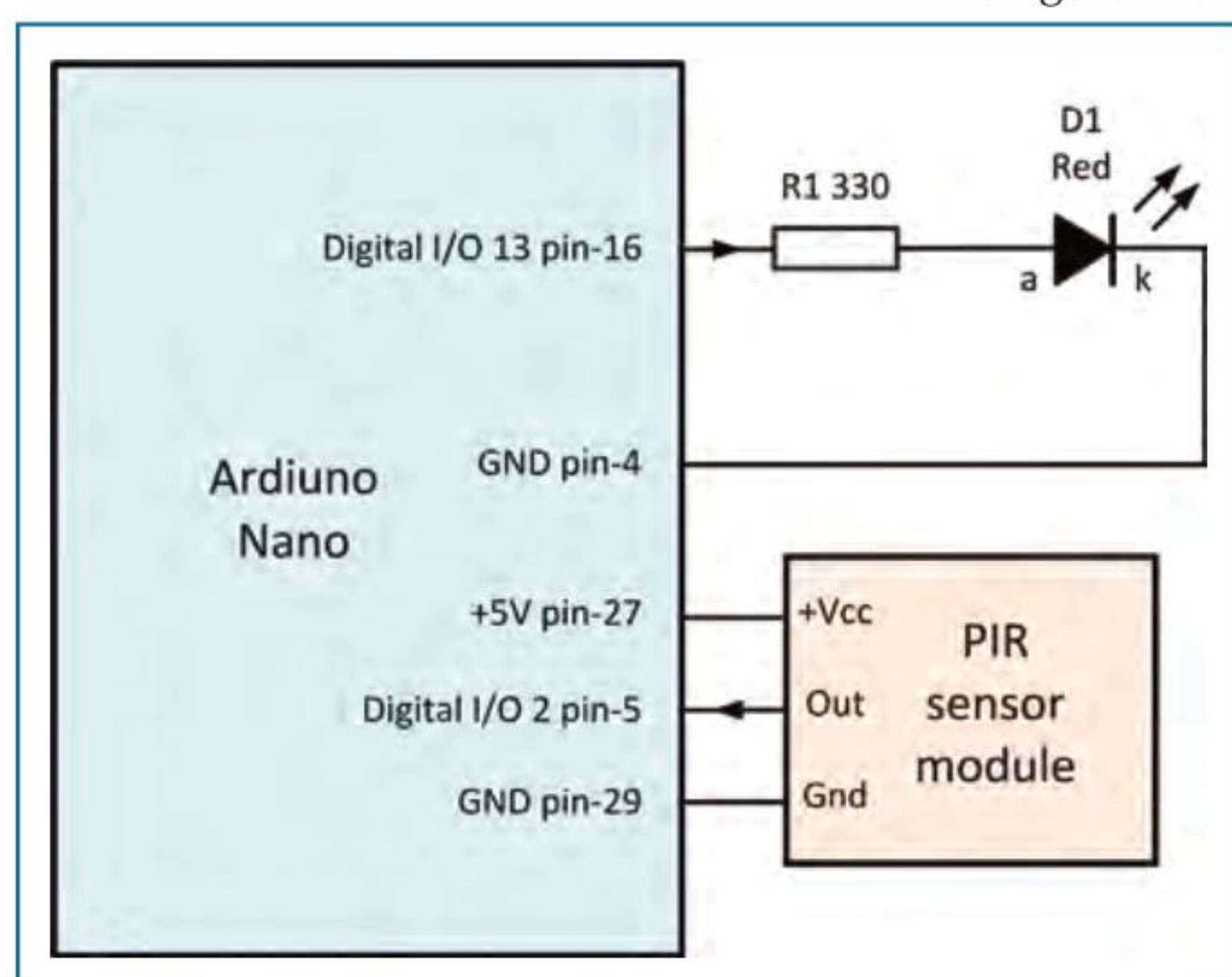


Fig.7.11. PIR sensor test circuit for use with an Arduino Uno or Nano

A simple PIR test routine is shown in Listing 7.1. This very simple code examines the state of the PIR output and then writes whatever state has been detected to the LED connected to digital I/O pin-13. When the PIR output is triggered into a high state the LED becomes illuminated. This routine will provide you with a handy way of quickly testing a PIR sensor and assessing its coverage.

Adjustments

After a moving target has been detected, the output from the PIR sensor module will go high for a period determined by the time adjustment (see Fig.7.12). This will hold the output high over a range extending from about 1 second (minimum) to about 20 seconds (maximum). Note that when single trigger operation has been selected, there is a delay of about one second before the output changes from a low to a high. The remaining potentiometer provides sensitivity adjustment over a typical target range extending from about 1m to a maximum of about 6m.

Trigger options

The board may be configured for two different trigger modes. The desired mode can be selected by means of the link at the extreme left corner of the board shown in

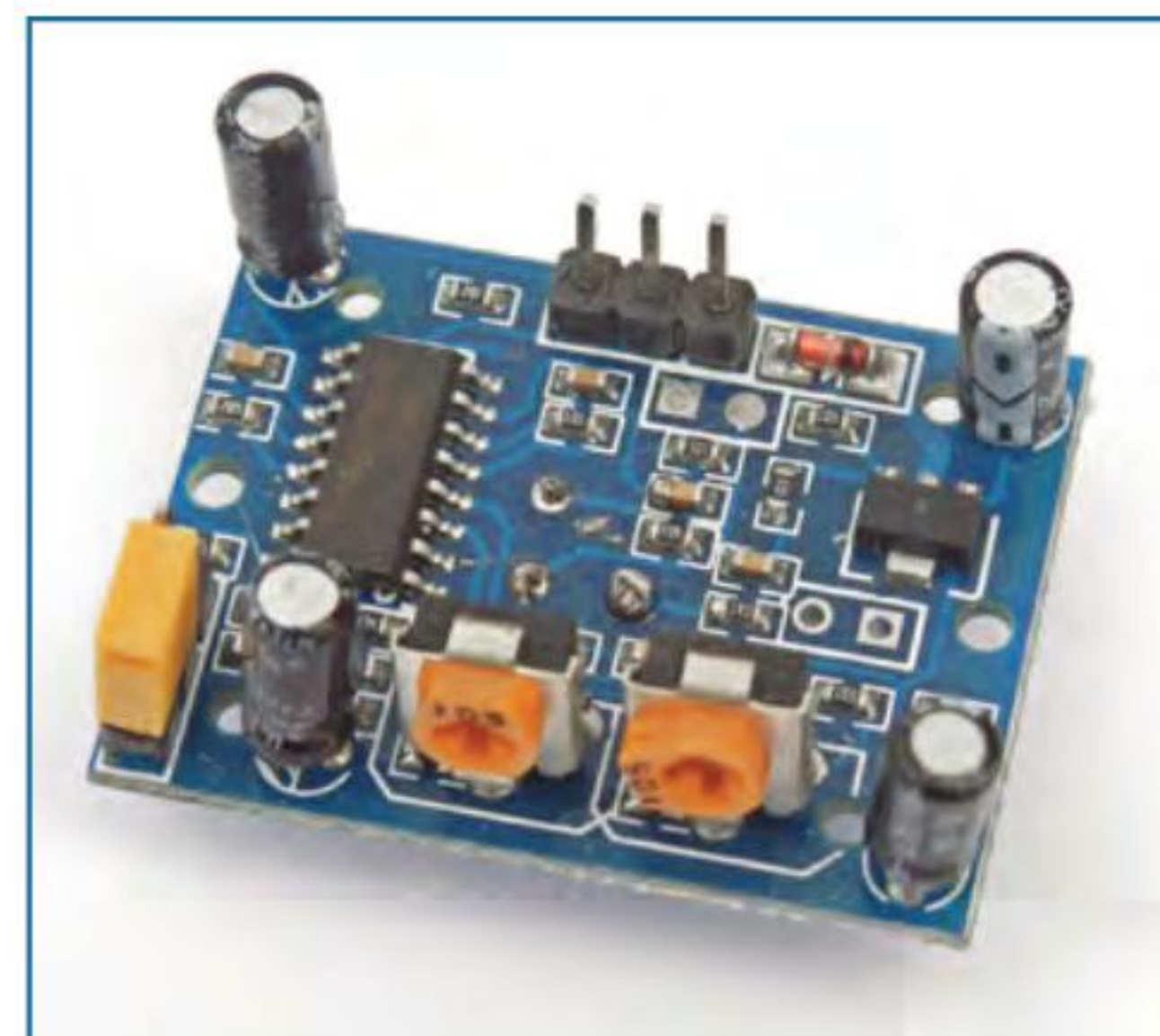


Fig.7.12. Rear of the PIR sensor showing the trigger link (left) together with the sensitivity (centre) and time (right) adjustments. The three pins at the rear are (left to right) ground, output and positive supply

Fig.7.12. The trigger mode can be set for either single triggering or for continuous retriggering. In the former (single trigger) mode the output from the PIR sensor will turn on and off as a target moves through its field of view. In the continuous retriggering mode, the output from the PIR sensor will continue to remain in the high state for as long as motion is detected. In this mode the output from the sensor will remain high for as long as the target is within range and is moving.

Coding Quickstart: generating tones

For some applications it can be useful to generate a signal in the form of an audible tone. The Arduino is able to do this easily using the `tone()` function. This handy function generates a square wave with a 50% duty cycle at a specified frequency. The tone can be generated for a specified period of time or, if a time is not specified, it will continue until a call to the `noTone()` function is made. Unfortunately, only one tone can be generated at any particular time, although several tones can be generated in quick succession in order to produce a musical sequence.

The tone can be generated on a specified digital output pin and then fed to a sounder or loudspeaker. Note that if a tone is already playing on a different pin, a subsequent call to the `tone()` function on a different pin will have no effect. If the tone is playing on the same pin, the call will just change its frequency. So, if you need to generate different frequencies on multiple pins, you will need to call `noTone()` on one pin before calling `tone()` on the next pin.

With the exception of the Arduino Mega, the `tone()` function will interrupt any PWM output on digital output pins 3 and 11. The `tone()` function is unavailable on the Due and Gemma versions of the Arduino.

The range of frequencies that can be

generated on the Uno (and other AVR boards) can range from 31Hz to 65,535Hz, more or less covering the entire audio spectrum. Here's an example of generating a five-second burst of 400Hz square wave on digital I/O pin-5:

```
tone(5, 400, 5000); // generate 5s of 400Hz
on pin-5
```

Note how the first parameter is the digital I/O pin number and that this is followed by the frequency (in Hz), and (optionally) the duration (in ms). Here's a further example that will generate just one second of 1.75kHz, this time on pin-2:

```
tone(2, 1750, 1000); // start beep sound on pin-2
```

And here's an example where a signal is generated for an unspecified duration:

```
tone(4, 648); // start beep sound on pin-4
// now do something else for a while ...
noTone(4); // stop beep sound some time later
```

Now, here are a few sound effects that you might want to incorporate in your project's code:

```
// Start low and go high (output on pin-5)

int toneFrequency = 100;
int holdTime = 100;

void setup() {
  while (toneFrequency < 1000) {
    tone(5, toneFrequency);
    delay(holdTime);
    toneFrequency = toneFrequency + 100;
  }
  noTone(5);
}

void loop() {
}
```

```
// Two tone siren (output on pin-5)
```

```
int count = 4;
void setup() {
  while (count > 0) {
    tone(5, 850);
    delay(1000);
    tone(5, 820);
    delay(1000);
    count = count - 1;
  }
  noTone(5);
}

void loop() {
}
```

```
// Start high and go low (output on pin-2)
```

```
int toneFrequency = 1000;
int holdTime = 100;

void setup() {
  while (toneFrequency > 100) {
    tone(2, toneFrequency);
    delay(holdTime);
    toneFrequency = toneFrequency - 100;
  }
  noTone(2);
}

void loop() {
}
```

Finally, Listing 7.2 is an example of using an Arduino Uno as a simple square wave signal generator that produces a variable output from 50Hz to 5kHz in two switched ranges when controlled by a potentiometer with its slider connected to analogue input A0 (see Fig.7.13). Note that we've not shown any supply connections on this circuit, but you can power the circuit from the USB connector or via an external DC input in the usual way.

Notice how this example uses the extremely useful `map()` function that maps a variable from one range to another.

Get Real: wireless-linked rain alarm

In this month's *Get Real* we will be describing another useful project – a simple PIR motion alarm. The unit uses a low-cost PIR sensor together with an Arduino Nano and a small loudspeaker. The complete circuit of the simple PIR intruder alarm is shown in Fig.7.14. The loudspeaker should ideally have an impedance of around 40Ω, but lower impedance units will also work. The value of series resistor R1 can be varied to alter the output volume, but should not be less than 150Ω.

Listing 7.2 Simple Arduino square wave signal generator

```
/* Square wave signal generator (output on digital I/O pin 2)
Frequency adjustable from 50Hz to 5kHz in two ranges */

int rangeSwitch = 3;
int frequencyControl = A0;
int toneFrequency = 500;
int rangeSetting;
int frequencySetting;

void setup() {
}

void loop() {
  // Get the range setting
  rangeSetting = digitalRead(rangeSwitch);
  // Get the analogue input from the potentiometer:
  frequencySetting = analogRead(frequencyControl);
  // Map the analog input into the required range
  if (rangeSetting == LOW) {
    toneFrequency = map(frequencySetting, 0, 1023, 50, 500);
  }
  else {
    toneFrequency = map(frequencySetting, 0, 1023, 500, 5000);
  }
  // Output the tone
  tone(2, toneFrequency, 10);
}
```


You will need

Arduino Nano microcontroller
USB cable with miniature-USB connector (for programming only)
Computer with an available powered USB port (for programming only)
1 low-cost PIR sensor module (see text)
1 SPST switch, S1
1 miniature push-button, S2
1 small loudspeaker, LS (see text)
1 220Ω resistor, R1 (see text)
1 330Ω resistor, R2
1 4.7kΩ resistor, R3
1 red LED, D1
1 9V battery, B1
1 small piece of stripboard
Connecting wires

Code

The complete code for the simple PIR intruder motion alarm is shown in Listing 7.3. The code is straightforward and, as usual, we've liberally commented it in order to help you understand what's going on. The code does not require any libraries.

As with our previous *Get Real* projects, the code should first be entered into the IDE and then saved before compiling and uploading it to the Uno, as described in last month's *Arduino Workshop*. When you have debugged and corrected your code don't forget to save it by clicking on 'File' and 'Save' or 'Save As...'. Next, click on 'Sketch' and 'Verify/Compile'. Any compilation errors will then be reported in the window at the bottom of the IDE.

Testing and adjustment

When you've corrected any coding errors that the compiler reports you will be ready to upload your code to the Nano. Just click on the upload arrow and watch the progress report. After the Nano performs a reset you should find that the LED (D1) becomes illuminated and a tone is generated by the loudspeaker when you pass your hand over the sensor module. The LED and tone should both remain latched on until the reset button (S2) is pressed. At this point the PIR motion alarm is placed back in the active state waiting for another target to appear and move within the protected zone. Having confirmed that the PIR motion alarm is working, the next step is to check the adjustments on the PIR sensor module (as described earlier). With a little experimentation it should be possible to achieve the correct triggering, time and sensitivity.

Going further

As always, there's a great deal of scope for going further with this month's *Get Real* project; for example:

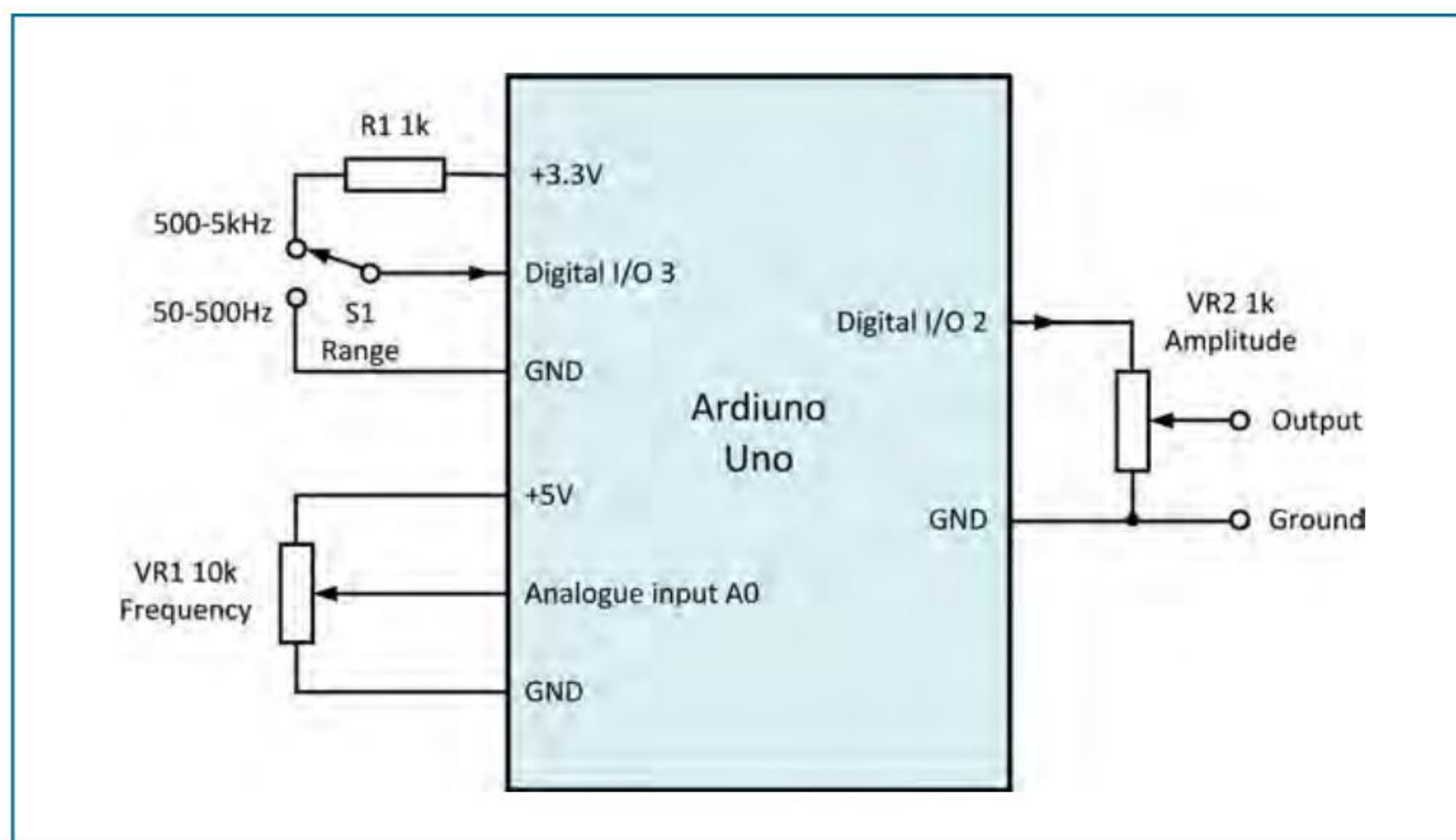


Fig.7.13. Arduino variable square wave generator connections

Listing 7.3 Code for the Arduino PIR motion alarm

```
/* Simple PIR motion alarm for the Arduino Uno or Nano */

// Inputs and outputs
int inputPIR = 2;           // Input from the PIR sensor
int inputReset = 4;         // Input from the reset button
int outputLED = 13;         // Output to the LED indicator
int outputSounder = 3;      // Output to the alarm sounder
// Variables
int oldState = LOW;         // Initialise PIR state (no motion yet)
int currentState = LOW;     // Current PIR status
int resetState = LOW;       // Reset button state

void setup() {
  pinMode(inputPIR, INPUT);    // PIR input
  pinMode(inputReset, INPUT);  // Reset input
  pinMode(outputLED, OUTPUT);  // LED output
  pinMode(outputSounder, OUTPUT); // Sounder output
  tone(outputSounder, 1150);    // Beep to confirm ready status
  delay(1000);
  noTone(outputSounder);
}

void loop(){
  currentState = digitalRead(inputPIR); // Check the PIR state
  resetState = digitalRead(inputReset);
  if (resetState == LOW) {               // System currently active
    // Wait for a change in level and then latch the alarm on
    if (currentState == HIGH) {          // Has it gone high and
      if (oldState == LOW) {             // was it low before?
        digitalWrite(outputLED, HIGH);   // Turn the LED on and
        tone(outputSounder, 850);        // sound the alarm
        delay(100);
      }
    }
  }
  else {                                 // Reset has been operated
    digitalWrite(outputLED, LOW);        // Turn the LED OFF and
    noTone(outputSounder);               // stop the alarm
    currentState = LOW;                  // Reset the system
    tone(outputSounder, 1150);           // Beep to confirm ready
    delay(1000);
    noTone(outputSounder);
  }
}
```

- Instead (or perhaps, as well as) producing a sound output a suitably rated relay could be used to energise a remotely placed bell or security light
- A time delay (typically 15 to 25 seconds) could be incorporated to allow the user

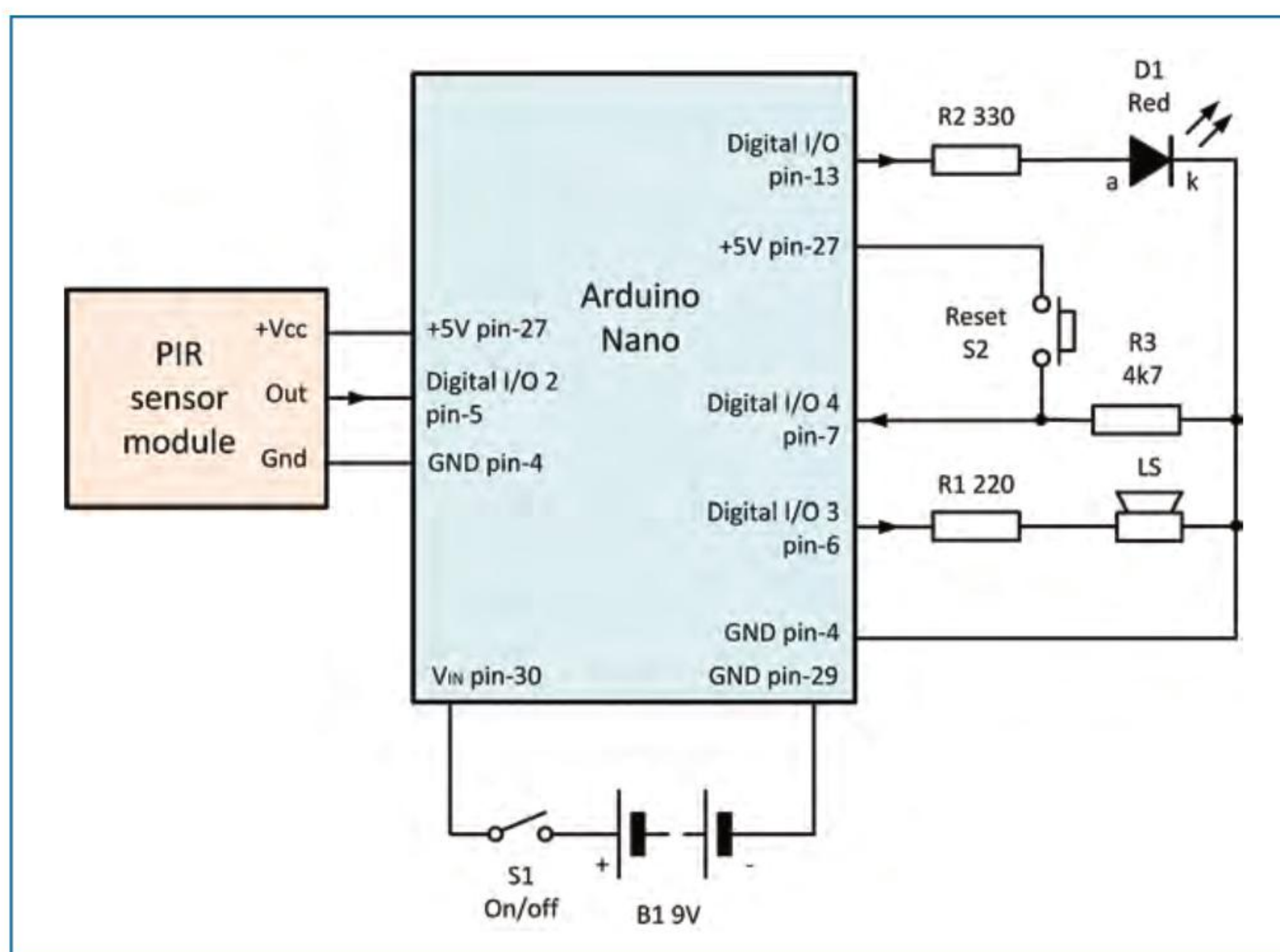
- to vacate the protected area when the alarm has first been switched on
 - A further LED could be added to show that the PIR alarm is active and waiting for a trigger event.
- All of these additions could be very

easily incorporated into the basic PIR motion alarm and will provide you with opportunities to develop your coding skills.

Next month

In next month's *Teach-In 2016 Arduino World* we will continue this month's infra-red theme by looking at a simple IR remote control based on the Arduino Uno and Nano. *Arduino Workshop* will introduce you to infra-red transmitters and receivers, while our programming feature, *Coding Quickstart* will introduce the infra-red remote library. Finally, our *Get Real* project will describe the design and construction of an Arduino multi-channel infra-red remote controller that will allow you to control your lighting, heating, doors, windows and a host of domestic gadgets from the comfort and security of your armchair.

Fig.7.14. Complete circuit of the simple PIR motion alarm



Correction to software in Teach-In 2016 – Part 3

Oooops!

Our apologies to reader; there is an error in one of the software listings accompanying this series. In April's issue, containing *Teach-In 2016 – Part 3*, Listing 3.4 was truncated and code was

omitted. To run the code successfully, the part in black below needs to be *added to the end* of Listing 3.4, after the final curly brackets (shown in red).

We thank Simon Bond for alerting us to our mistake.

Listing 3.4 Code for the simple Arduino based access control system

```
/* Arduino access control system */
...
...
}
}

void checkPasscode() {
    if (password.evaluate())
    {
        lcd.setCursor(0, 1);
        lcd.print("* Welcome *"); //
        digitalWrite(outRelay,HIGH); // Activate relay
        delay(1000); // and wait 1s
        digitalWrite(outRelay,LOW); // Deactivate relay
        delay(1000); // afterwards
        lcd.setCursor(0, 1);
        lcd.print(" ");
        password.reset(); // Reset passcode after valid entry
    }
    else
    {
        lcd.setCursor(0, 1);
        lcd.print("* Invalid *");
        delay(1000);
        lcd.setCursor(0, 1);
        lcd.print(" ");
        password.reset(); // Reset passcode after invalid entry
    }
}
```



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PICs and the PICkit 3: A beginner's guide – Part 3

WELCOME to Part 3 of our beginner's guide to PICs and the PICkit3. In parts 1 and 2 of this guide, we covered some of the basic concepts behind PIC development – from microcontrollers and microprocessors, programmers and demo boards to compilers and IDE's. If you've been following along, then I'm sure you're eager to get stuck in. Alternatively, if you haven't read the previous issues, I recommend getting your hands on them before moving forward. It's not necessary, but it will make things a lot easier to understand.

Our tools

Picking up where we left off from last month, we installed Microchip's MPLAB X IDE and the XC8 compiler, as well as the *PICkit 3 Starter Guide*. Here's the links again:

1. Download *PICkit 3 Starter Kit User's Guide* (<http://tinyurl.com/jyqfeuk>)
2. Download MPLAB X IDE (<http://tinyurl.com/hmehqja>)
3. Download XC8 Compiler (<http://tinyurl.com/h5g9k5l>)

Hopefully you've received your PICkit 3 Low Pin Count Demo Board, Programmer and USB Cable. If not, you can obtain them from the links below. From now on you will need them to follow the series:

1. Purchase the PICkit 3 Low Pin Count Demo Board (<http://tinyurl.com/h2jj2ek>)
2. Purchase the PICkit 3 Programmer + USB Cable (<http://tinyurl.com/zcp3le>)

Hands on

In the last two months I've talked a lot about the concepts behind PIC development and the tools that we use. What we really want though, is to get stuck into some development. I'm a big fan of practical hands on learning. While it is great to understand theory, I find it all comes together once you see it physically working in front of you. What better way to see something working than turning on an LED?

We should have all of our tools at the ready now. We're going to start off with the *PICkit 3 Starter Kit User's Guide*, mentioned above. This guide talks about some of the

technology inside our microcontrollers and how they work. It also gives a number of lessons, which we can leverage to learn about PIC development. I'm not going to copy the contents of the user guide itself, that would be pointless. However, I am going to walk through the document making recommendations on various parts and assisting in some of the more difficult sections. The lessons do not give us all the necessary code and steps to get each project working, but they do give us enough to figure it out for our ourselves. These are the parts I will fill in and ensure we get each lesson working.

We could work through the PDF on screen, but if you're like me and prefer to have a physical piece of paper to read from – and even more importantly, to make notes on – then print it off. At 101 pages, the PDF is a little on the large side to print off completely. So, help the environment, save some trees, and only print Chapter 3 – *Lessons*.

The user guide is split into three chapters: *Overview*, *MCU Architecture* and *Lessons*. It's a good idea to read over the first two chapters as these will give you a background to the demo board we'll be using and a detailed guide to the internal workings of the PICs themselves. It's alright if you don't fully understand them, I will return to explain some of them later in our tutorial series. Try to read section 2.16, it covers some programming basics, which will be invaluable moving forward. We could go into greater detail on the internal architecture, but to be honest, I just want to jump straight in and get my hands dirty. We can come back to our internal operations at a later date when they are needed.

Lesson 1

The first lesson on page 39, covers one of the most important features in any microcontroller development: turning on an LED. It doesn't matter how complex your project or product is, in my opinion the LED is the most useful component in any design because it can tell us exactly what is going on. In this case, we will know that our code is doing exactly what we want it to do, just by turning on.

The lessons themselves are covered first in Assembly and then in C programming languages. I'm a huge fan of C as

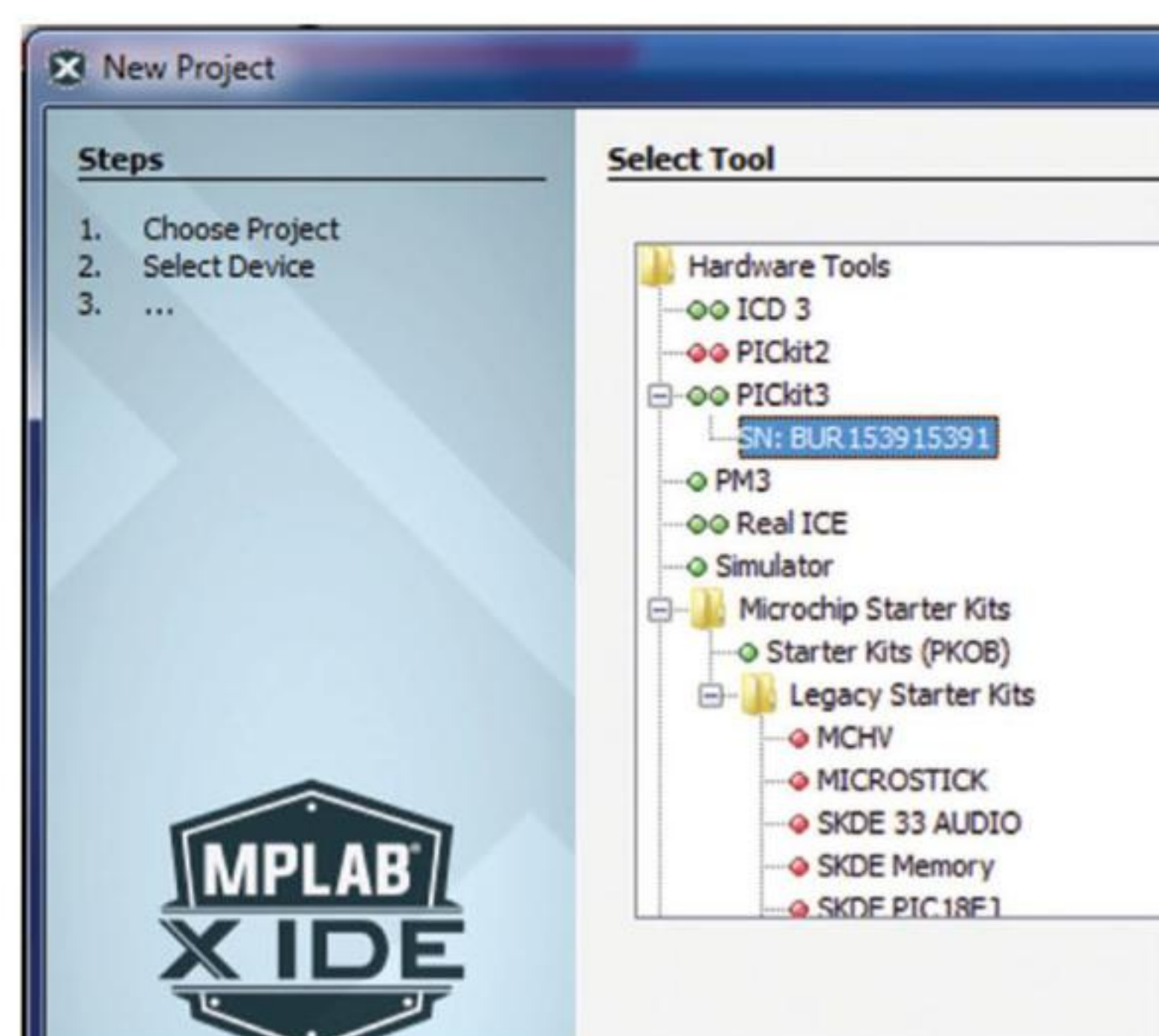


Fig.1. New Project → Select Programmer tool

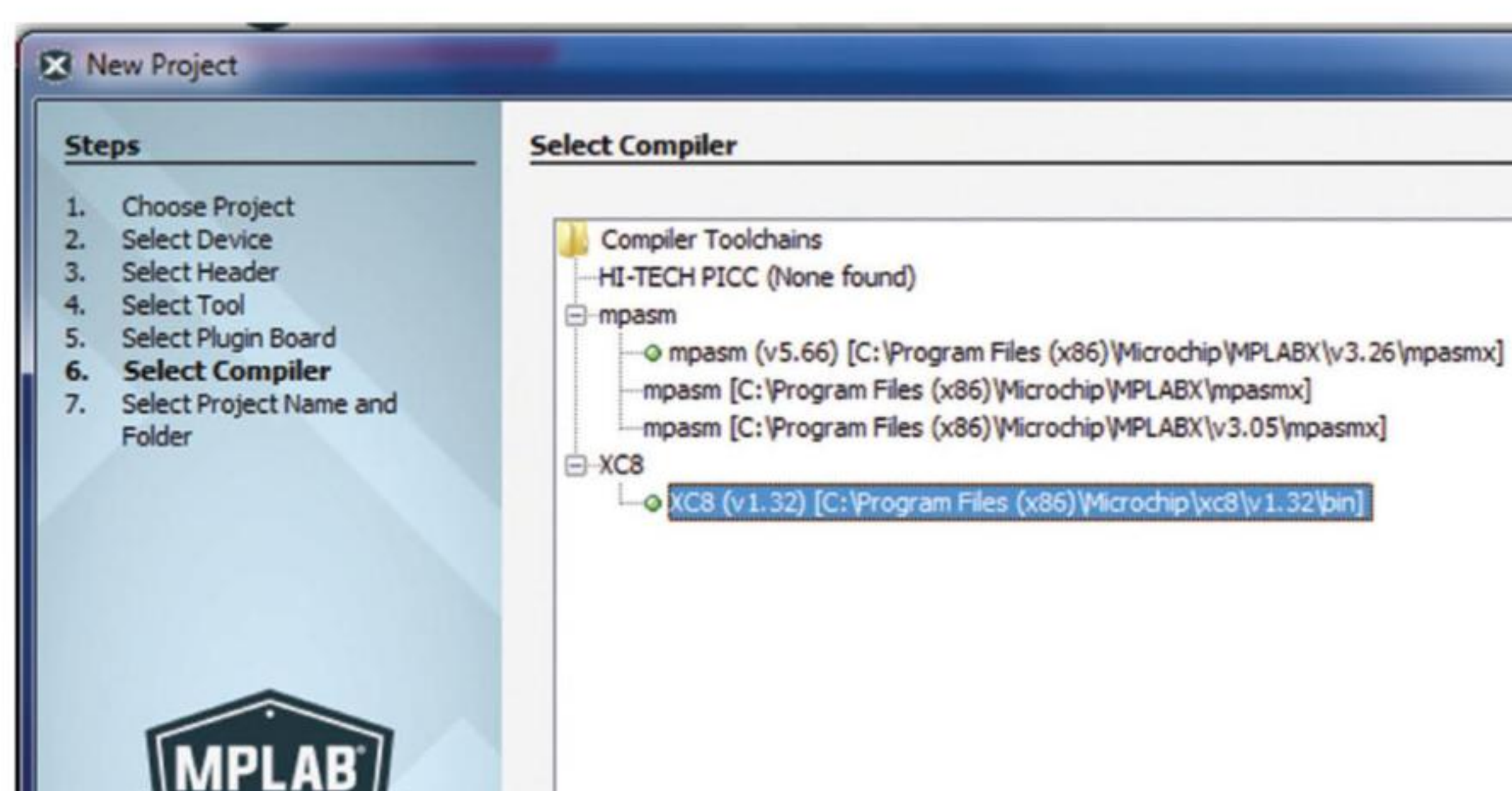


Fig.2. New Project → Select Compiler

it is much more intuitive to use, it reads like English. On the other hand assembly can be very powerful when you're looking for complete control of your project with regards to strict timing. Other advantages include reduced compiled code size, faster code operation and decreased power consumption. However, it's not really beginner friendly. You can work through the lessons using either one or both.

Setup new project

Now the lesson gives us an explanation and the code to run it, but it lacks the 'how'. Open up MPLAB X from wherever you've installed it on your system. You should see the Getting Started Page now. We're going to start a project from scratch.

1. In the File menu in the top left, select New Project. This launches the New Project window. We could do other things here like create our own library or import from MPLABV 8.x. We're going to stick with the default. Microchip Embedded and Standalone Project and Standalone Project should already be selected – so, click Next.
2. Now we select which microcontroller device we're going to use. Change the device in the drop down menu to the PIC16F1829. This is the microcontroller we'll be using on our demo board. Click Next again.
3. We're not using any debug header at the moment, so leave this as the default – None in this window and click Next again.
4. Here we choose our debugger, which is the PICkit3. If our PICkit 3 programmer is connected, it should be highlighted in green with the serial number below it, as shown in Fig.1. Click Next again.
5. Now we need to select our toolchain. Here we can choose between using our C compiler or our Assembly compiler. We're going to start with the C compiler. The XC8 compiler should be installed already, which should now be selectable here, see Fig.2. Click on the XC8 compiler and click Next.
6. Here, we need to choose a project name and project folder. Choose the project folder you want and let's name our project 'lesson1'. Click Finish – we're done creating the project.

We should now see our project folders on the left-hand side of the screen. Right click on Source Files and select New. I'm going to start off with the Example 3-6 Code on page 45 of the user guide, so we're going to select main.c from the New menu. You'll be asked to name the new file, I just call it main.c. Once we've finished that, our code window should be open on the right hand side.

Copy the code from the example in the user guide into your main file, replacing everything else. Save the project (File → Save, or Ctrl-S). Quick tip, when coding – **SAVE OFTEN!**

Building our code

Our code should compile straight off. We do this by selecting Run from the menu. Then we select Build Main Project. We should see in our Output window in the bottom left: BUILD SUCCESSFUL (total time: 102ms).

You may notice two red circles with an exclamation mark in Fig.3. This is an error in our code, by hovering the mouse over it, it gives us an abstract error message: unexpected token. There was a migration in the behaviour of the `__CONFIG` macro to the `#pragma config` directive instead in MPLAB X. The code will still build and do what we want it to do, but in the interest of correctness, we should really replace those two lines with the following lines of code and build our code again.

```
#pragma config FOSC=INTOSC, WDTE=OFF, PWRTE=OFF,
MCLRE=OFF, CP=OFF, CPD=OFF, BOREN=ON,
CLKOUTEN=OFF, IESO=OFF, FCMEN=OFF
#pragma config WRT=OFF, PLLEN=OFF, STVREN=OFF,
LVP=OFF
```

Now we're ready to program the demo board. Plug the PICkit3 into the demo board, as shown in Fig.4. Note the little white arrows line up to indicate pin 1 of the connectors. Don't forget to plug the PICkit3 into a free USB port on your computer. Since the board doesn't have its own power supply, we will need to power the demo board from the programmer.

1. This can be achieved by opening Project Properties in the File menu. This opens up our Project Properties window, seen in Fig.5.

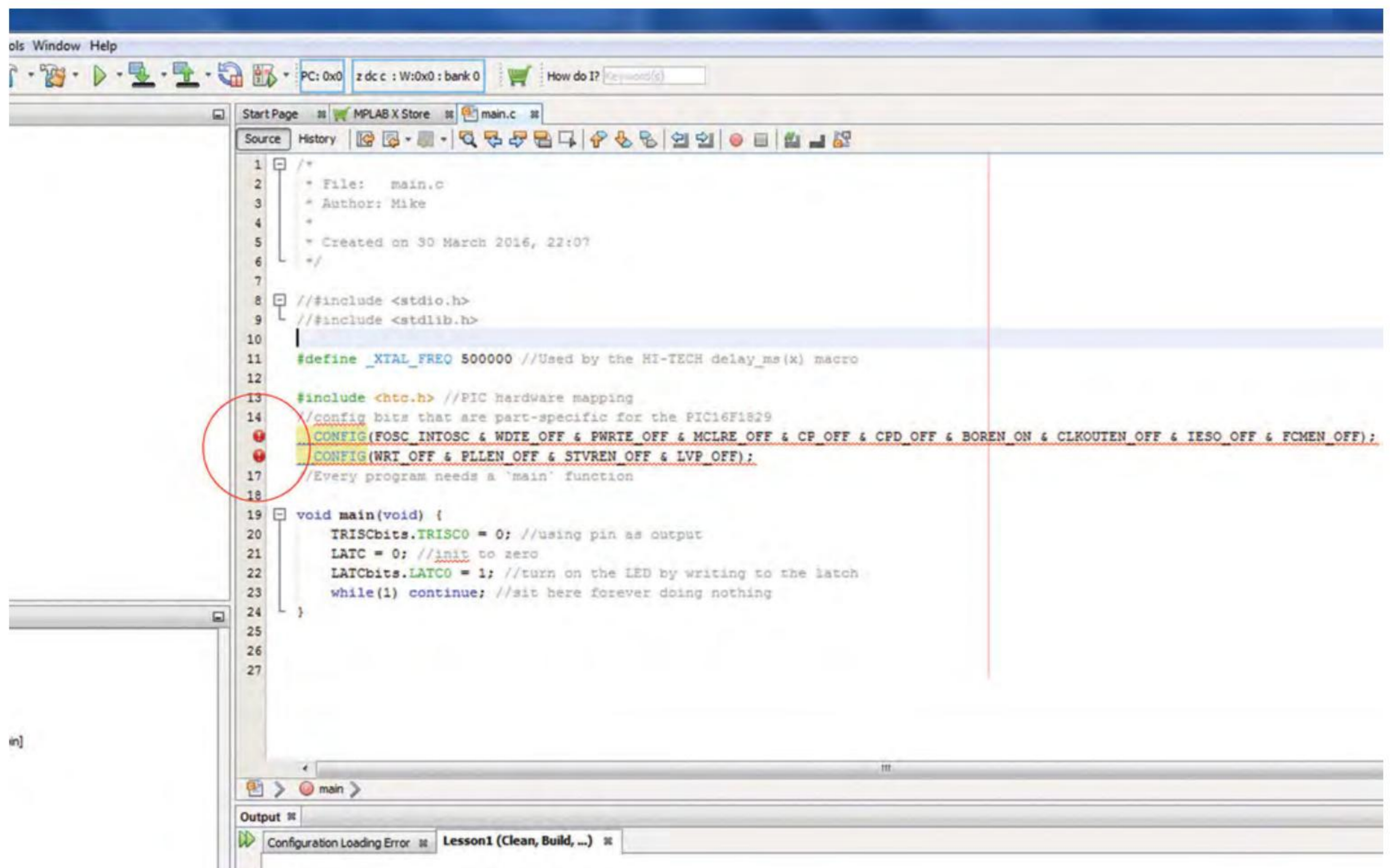


Fig.3. MPLAB X IDE Lesson 1 project successfully built



Fig.4 . Microchip's PICkit 3 plugged into PICkit Low Pin Count Demo Board

2. Under the section Categories, select the PICkit3.
3. In the top middle of this window under Option Categories, change the drop down menu to Power.
4. Tick the Power Target circuit from PICkit3 box. Note in the datasheet that the voltage for the PIC16F1829 operates between 1.8V and 5.5V, so 5.0V is fine in this instance. You may get a warning about powering it with 5V when programming, this can be ignored as this board is 5V tolerant.
5. Click Apply to complete.

First time programming

To program the demo board for the first time, we can either go to the Run menu and select Run Main Project or press F6 on the keyboard. The two LEDs, DS4 and DS3 on the demo board should flash while it is being programmed. Once complete, DS1 LED should be on, see Fig.4. Like I mentioned

earlier, this is the real beauty of LEDs, showing us that our code works. It may seem like a small accomplishment, but this is where it all starts. We will build upon this in the following issues.

If you want to work through the assembly code, you can follow through the same steps above with the following changes:

1. Instead of using the XC8 toolchain, you'll need to select mpasm in our toolchain selection (item 5 above). This is the assembly compiler built into the MPLAB IDE.
2. When adding a new file to the project, you may need to select AssemblyFile.asm instead of main.c. This opens up the new assembly file window. Enter the name 'lesson1' and press Finish.
3. Copy the code from Example 3-4 on page 43 into this new file.
4. From here, the steps above and the outcome are identical.

The rest of the lesson details what each line means in both assembler and in C. It also covers the use of the PIC18F14K22. This is another microcontroller, which comes with the demo board. This means pulling out the PIC and replacing it. You can do this if you want, but I'd recommend sticking with the original one for the moment and come back to it later if you're feeling adventurous.

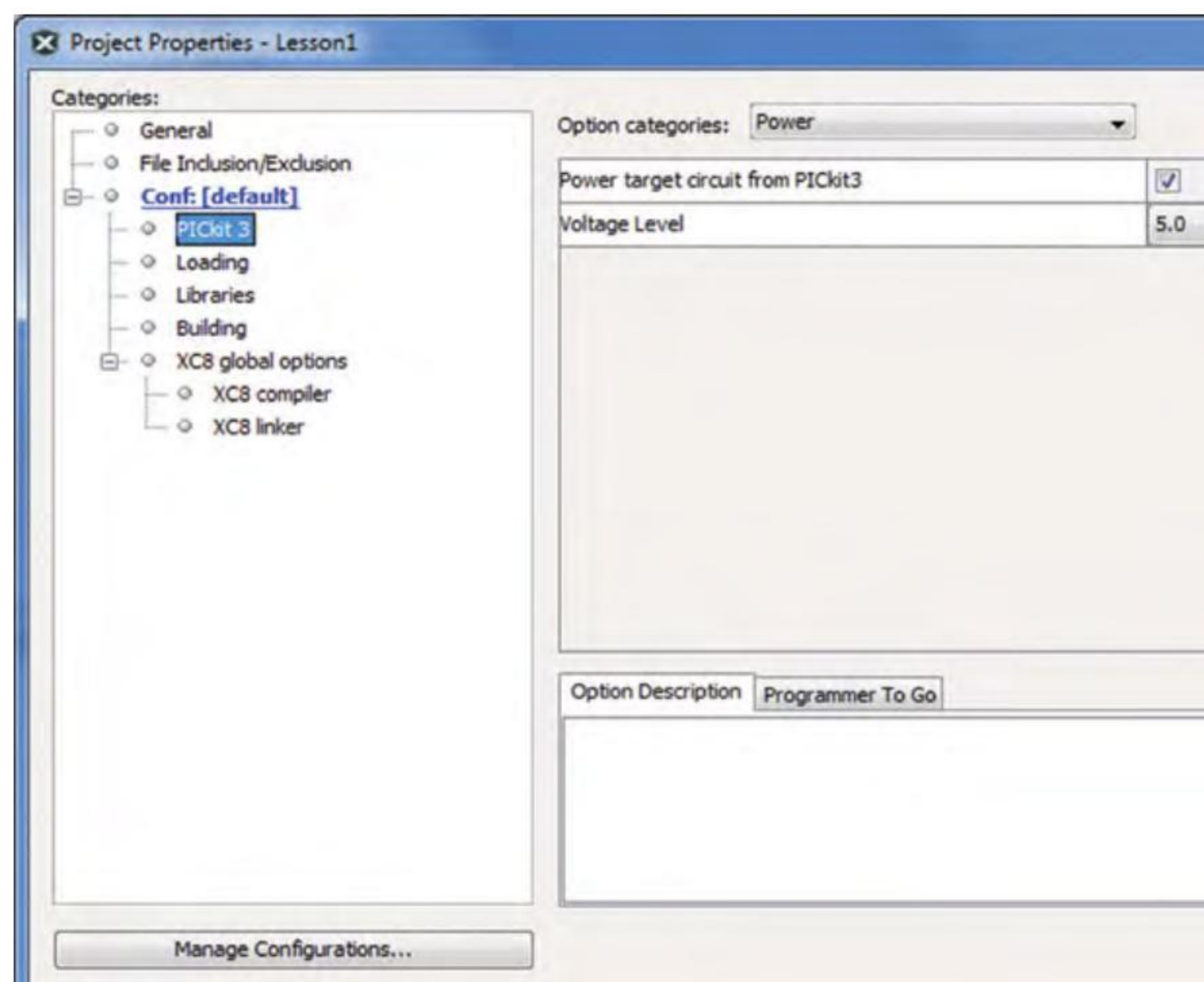


Fig.5. Lesson 1 Project Properties → Power Target circuit from PICkit 3)

Next month

We've made our first step into the world of PIC with our first lesson by programming our demo board and turning on a LED. Next month, I'd like to pick up the pace and cover the next two lessons. Feel free to work ahead through the lessons yourself. The lessons don't give you all the code, but they do give you enough to do it yourself. I have deliberately avoided discussing the actual code this month, but next month I will start to delve into what the code is doing.

Not all of Mike's technology tinkering and discussion makes it to print.

You can follow the rest of it on Twitter at @MikePOKeeffe, up on EPE Chat Zone as mikepokeeffe and from his blog at mikepokeeffe.blogspot.com

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NET WORK

by Alan Winstanley



Birthday greetings

THIS month's *Net Work* celebrates 20 years of bringing *EPE* readers news and views about Internet trends and developments. *Net Work* was spun out of the July 1996 issue, which carried an article, *The Internet: What's in it for you?* when the writer introduced the *EPE* readership to the emerging world of Internet access. The first *Net Work* column in *EPE* August 1996 greeted readers triumphantly with 'Welcome, internauts everywhere, to *EPE*'s very first *Net Work* column!' The term 'surfing' had yet to catch on.

It's sobering to think that there's now a demographic group – the so-called 'Generation Z' – that has never known life without Internet access (nor mobile phones, MP3s, computers or remote controls, for that matter). Nowadays the Internet is a near-universal utility service delivering news, websites, movies, television, sport events, video communications and entertainment in a way that was unthinkable 20 or 30 years ago – and certainly not 60 years ago, when the seeds of digital communications were first being sown. So where did the Internet come from, and who paid for it? This month's *Net Work* is the first of a two-part feature that delves into the Internet revolution and highlights some interesting milestones reached along the way.

Cold War baby

The origins of the Internet are well documented, and generally lie in the Cold War era that was dominated by the 'Iron Curtain'. To counter the possible threat from Soviet nuclear bombers in the 1950s, the US military needed to process incoming data from its radar stations, interpret the vectors to calculate the likely target and marshal any military assets that were in range – all in real time. The military built the country's enormous Semi-Automatic Ground Environment (SAGE) air defence system, which relayed computerised radar data to human operators (hence, 'semi-automatic') who analysed the screens before co-ordinating a response: all

this in an era of clattering teletype machines, punched cards and valve (vacuum tube) computers. The scale of this early electronic technology is virtually unbelievable, and a really fascinating Cold War USAF movie describing SAGE is worth watching at: <https://youtu.be/06drBN8nlWg>. An IBM movie about the SAGE computer system is at: <https://archive.org/details/OnGuard1956>; the large screens made great Hollywood movie props when SAGE was finally decommissioned.

By this time, the military was already grappling with the problems of transmitting data securely over a network and trying to computerise the response from end to end. The 1957 launch of Russia's Sputnik I, or more accurately the threat posed by the rocket that sent it aloft, sent shockwaves through the Pentagon. America's new Advanced Research Projects Agency (ARPA) was charged with the task of building a resilient communications and control network, a decentralised infrastructure designed to survive a nuclear attack. In 1968, ARPA's new digital communications project got under way, focussing on interconnecting and timesharing some ARPA-funded computer mainframes located in prime US academic sites, starting with UCLA and Stanford University in California. The Massachusetts-based advanced engineering company Bolt, Beranek and Newman Inc. (BBN) won the contract to design and build the network – now called ARPANET – from scratch.

Instant messages

Instead of using traditional circuit-switching communications, where (say) a landline had to be wholly committed to making a single call, ARPANET would send bursts of data in small 'packets' that could be sent efficiently around the network before arriving at their destination, where they would be reformed to make the message complete again. Error-correction techniques would re-transmit packets if needed, and packet communications could use a

multitude of dynamically-allocated routes instead of hogging a dedicated circuit. This distributed approach to communications would inherently survive any likely attack.

Within the year, BBN and UCLA had firmed up the core principles of implementing a digital packet-switching network, building on earlier research at the Rand Corporation and Britain's National Physical Laboratory (NPL), where the term 'packet' was first used. BBN designed an 'Interface Message Processor' or IMP, an almost military-grade machine containing a Honeywell DDP/ 516 general-purpose computer in a cabinet larger than a deep freezer. In effect, the IMP was the world's first router. A second IMP was installed at Stanford a month later and engineers successfully connected to the remote system over a telephone line. Famously, the first example of a true Internet transmission was the word 'login' typed into their IMP by UCLA staff as they tried connecting it to Stanford. Leonard Kleinrock of UCLA describes the moment at: www.lk.cs.ucla.edu/personal_history.html

By December 1969, ARPANET had four university hosts, three in California and one at the University of Utah, interconnected by 50kbps leased landlines. Press images show how six months later, the network had traversed the US to connect BBN, MIT and Harvard over in the east. More nodes were added and by September 1973, something else had happened: satellite circuits now connected Hawaii and Norway's seismic monitoring network NORSAR, the latter being the first such networked connection outside of the US. A Terminal Interface Processor (TIP) in Norway meant they could access the network directly without needing a host computer. Shortly afterwards, NORSAR was connected by a 9.6kbps link to University College London. This aggregation of networks would be the foundation of the Internet that we know today.

The early protocol for data transmission, Network Control Program (NCP) was replaced in the

mid 1970s by Transmission Control Protocol/ Internet Protocol (TCP/IP) to cope with the rising numbers of hosts that were connecting to the Internet, and TCP/IP became the standard that is in widespread use today. Put simply, TCP would manage the business of packaging up data ready for transmission, while IP would put an address label (an IP address!) on each packet, preparing it for transportation. TCP would then unpack the message again once it had been received, or it might ask for some packets to be sent again until the transmission was complete.

In the Ether

Some familiar tech brands of networking hardware originated from this same era. Ethernet was designed at Xerox as a way of networking their desktop computers using coaxial cable. Out of this came 3Com in 1979, which developed early Ethernet cards. Stanford also spawned Sun (Stanford University Network) Microsystems after devising a dedicated 'workstation', a computer that ran on a network, on the theory that multiple workstations would be more powerful than stand-alone machines. (Facebook now owns Sun's original HQ.) The 'router' also hailed from Stanford academics as a way of letting different university computer networks communicate across campus: Cisco Systems was spun out of this, originally financed by personal credit cards.

As the network 'backbones' continued to expand they would be utilised by military, commercial and academic institutions. In *Everyday Electronics*, May 1982 we reported on the 'Highway of the Future' and tests made using the latest transmission medium: glass fibres. British Telecom's 'Lightlines' research labs had succeeded in sending pulses of light over 100km of optical fibre, twice as far as they achieved in 1981. In the November 1982 issue we reported that Britain had opened the world's longest optical fibre link (204km), entering service on 22 July and replacing the London-Birmingham wire first built in 1887. The fibre allowed thousands of calls to be handled simultaneously, and BT would licence their new fibre manufacturing process to telecoms companies around the world. Fibre also formed the core of Britain's first, but ill-fated, national competitor to British Telecom, called Mercury, which laid new fibres alongside railway lines. Some readers may remember the blue Mercury button found on new phones and fax machines at that time.

Personal computers started to appear commercially in the late 1980s, along with networking software such as Novell's Netware. The IBM PC and IBM-compatible machines would allow businesses, academics and individuals to harness PCs for



Everyday Electronics, November 1982's news of the world's longest fibre optic link

themselves, and home computers such as the Commodore, Sinclair Spectrum and BBC gained a foothold in many schools and households at the time, becoming hobbies in their own right. People generally became more IT-aware, and graphical interfaces such as Microsoft Windows on the PC made personal computing technology more accessible and easier to use, helped by the new computer mouse.

Mail on the move

In an era of 1980s telexes and fax machines, the concept of communicating electronically when away from the office was gaining ground. We reported in *Everyday Electronics & Electronics Monthly* (April 1986) how Japan's Brother EP-44 offered a new solution containing 'everything you need to get started in electronic mail'. Brother's near-silent electronic typewriters were already biting into electric typewriter sales. It was claimed the EP-44 would benefit anyone who needed to write and send text quickly while 'on the move'. The machine had a 'teleprocessor' – a letter-quality thermal printer with an RS232C serial port, so it could double up as an electronic typewriter or a computer printer. Critical for mobile communications was its acoustic coupler, which allowed the machine to send and receive data electronically using a telephone's handset. The Brother EP-44 fitted into a briefcase for portability, and also included was a subscription to the One-to-One electronic mailbox service, which by then boasted of having 'over 6,000 users in the UK alone'. Special teleconferencing and email services such as Telecom Gold which used slow 300 baud modems were also appearing, as reported by Barry Fox in the July 1987 issue. The technology was far from user-friendly and Barry described some hair-pulling frustrations of trying to submit his copy electronically to the *Today* newspaper.

Modems could also be used for accessing a bulletin-board (BBS) so that files, updates and messages could be downloaded by dialling into remote servers via a landline, and users could participate in simple terminal-type chat as well. Despite early limitations and the somewhat clunky operation, the expansion of Internet-based services proved unstoppable. During the early 1990s, Internet access at home – as far as there was any – was anything but mainstream or cheap; it still relied on a modem connecting over a creaking POTS (plain old telephone system). Using a personal computer for going online was largely the province of technical enthusiasts, computer hobbyists and professionals or managerial users. Access services were popularised by America's CompuServe Information Service (CIS) that came to the UK, charging £10 for three hours of premium content. Subscribers could access carefully screened content using CompuServe Information Manager (CIM) software for Windows 98, which offered electronic mail, messages and forums. Users had inscrutable addresses such as 10537,1234@compuserve.com and the audio 'You have new mail waiting!' message became a familiar sound eagerly anticipated by expectant users. CompuServe UK provided the writer with his first photo download: an image of the Horsehead Nebula captured by NASA's Hubble. I pinned this achievement on the noticeboard for months. *EPE* abandoned an early idea to host a CompuServe forum of its own, though.

The rise of ISPs

Soon it seemed like every computer user had hooked a modem onto their serial port, notably the popular US Robotics Sportster, and the twinkling LEDs of these screeching bone-coloured boxes became a familiar sight. As the 1990s Internet market continued to evolve in Britain, an alternative to the closed shop of CompuServe emerged – dial-up



The Brother EP-44 was a 1980s mobile email terminal and electronic printer. The acoustic coupler allowed a phone handset to be connected for transmitting data 'on the go'

Internet access was offered by a new breed of 'Internet Service Provider' (ISP). London's Demon Internet was something of a maverick ISP that popularised the 'TAM' (ten pounds a month) flat-rate account. The writer coined 'epemag' as a Demon Internet username when signing up for a TAM account in February 1995, one of Demon's first 40,000 subscribers. It was originally created solely for *Circuit Surgery*. Demon wrote back on Conqueror headed notepaper with details of a login!

Early dial-up Internet access was very much a lottery, though, due to the paucity of access lines and the author's 14.4k modem, churning inside a 486 PC, often made scores of failed attempts each night before finally connecting to the local Point of Presence (PoP). At one time, the author's phone bill was 25-pages long, full of local-rate calls to Demon's nearest point of presence. Internet access would gradually grow with endless numbers of faster modem racks being installed by ISPs and more optical fibres spanning the country. Being immune to outside interference, some optical fibres were also wrapped around catenaries of overhead power cables as a clever way of traversing the countryside.

EPE steps online

The need for *EPE* to go online was spurred on by the advent of the PIC micro as we started publishing PIC-based constructional projects in the 1990s for the first time. These often involved distributing PIC source codes and other files to readers to enable them to 'burn' their own chip. Instrumental to this was the publication in February 1996 of a *Simple PIC Programmer* by Derren Crome, and the PIC revolution then got under way. Looking back, *EPE* had always striven to distribute files in whatever format our readers needed, and over the decades we even offered computer listings on tape cassettes or floppy disks, for example. Readers following various *EPE* computer tutorials – many written by our own Mike Tooley – could purchase them by mail order and a tape cassette with (say) Sinclair Spectrum files would pop into their mailbox a week or two later. Apart from the cost of publishing files in different formats this way, mail order made our material less accessible to our overseas readers, who often suffered frustrating delays due to the postage system both ways.

With the microcontroller hobby project market taking shape fast, *EPE* took the lead by offering project source codes free of charge, and I recall holding various online conversations about this with users in the mid 1990s. The idea of dealing with a multitude of like-minded users and communicating with them 'online' took shape in Usenet, which I will describe next month. To get source codes into the hands of our readers quickly and cheaply, there was no doubt about it – *EPE* would have to go online! Consequently, *EPE* set up a file area on a server located in nearby Southampton. The File Transfer Protocol (FTP) was, and still is, one of the founding tenets of the Internet, and <ftp://ftp.epemag.wimborne.co.uk> was born in 1996 and still runs today in Birmingham, hosting legacy files maintained for retro-compatibility with our back issues. Writing *Circuit Surgery* at that time, I found that

'anonymous FTP' was a great way of distributing the Surgery's 'Ni-Cad FAQ', a document about rechargeable batteries, and my UK Sources FAQ – a directory of component suppliers that could be downloaded via FTP. Those *EPE* readers who did not have Internet access wrote to me asking for a hard copy instead, which I duly printed off and posted to them.

Spinning a web

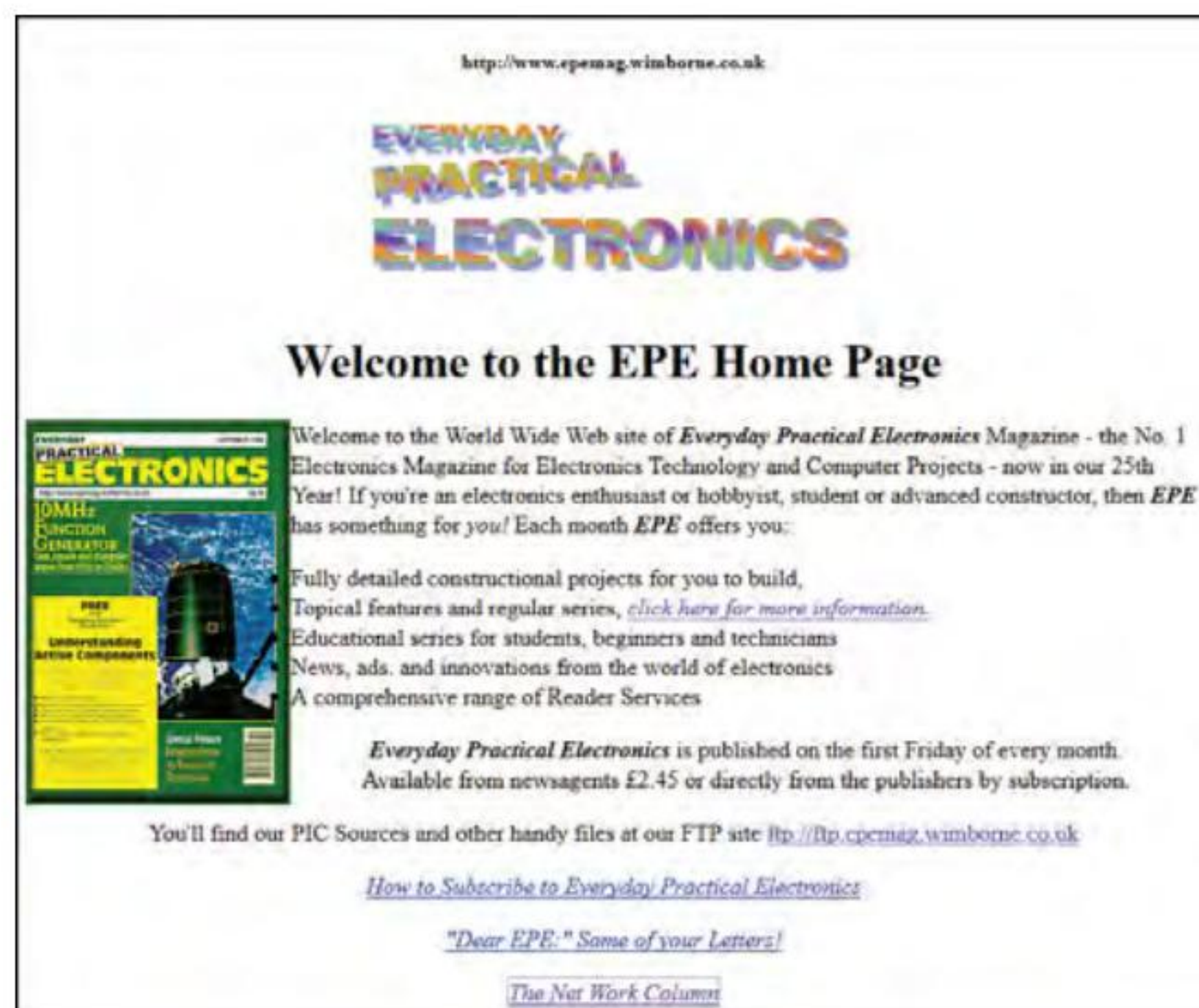
The birth of the worldwide web at CERN is well documented and, with the nascent web barely taking shape in the 1990s, the author loaded some basic HTML files onto CompuServe's web servers in the US, where just a few hundred kilobytes of space were offered to each user. Software such as SoftQuad HoTMetaL Pro, which helped users to code HTML web pages, arrived on the market. In 1996, *EPE*'s first website went online, hosted in Southampton and those very early pages are archived at: www.epemag.wimborne.co.uk/legacy/oct96www. Overseas readers could finally 'check in' at our website in real time, if only to get a feel for what was coming in the next issue. Free webspace for hobbyists also sprang up in the UK, and some early adopters complained of being penalised because their websites were proving 'too popular' and getting too many hits! The need for bandwidth restrictions and traffic quotas started to form as the worldwide web took hold.

In next month's follow-up article, I'll highlight the turning point that signalled the start of the mass uptake of Internet access, along with developments to take us to the present day (and beyond). You can email the writer at: alan@epemag.demon.co.uk

Download a PDF copy of the original July 1996 article – The Internet: What's in it for you? – from: www.epemag.net/epe-network.html



CompuServe Information Manager for Windows offered email and forums to subscribers



EPE's first website was simple, but it brought instant engagement too!

INTERFACE

Capacitance Meter Mk2

THE PREVIOUS *Interface* article considered the uses of a binary counter in conjunction with a Raspberry Pi computer, and featured a random number generator. The *Interface* article prior to that one described an ultra-simple capacitance meter based on a monostable circuit and the timing facilities provided by the Python programming language. As explained in that article, timing accuracy was limited by factors such as the use of interrupts in the normal running of the Raspberry Pi and the operating system. This made it difficult to obtain a high degree of accuracy using this method.

It was proposed that an external clock oscillator and a counter circuit, together with a monostable timer, would give better results while still offering a reasonably simple and cost-effective approach. This alternative method is used in the capacitance meter add-on featured in this *Interface* article. It is effectively the counter from the random number generator, the monostable from the original capacitance meter adapter, plus a simple clock oscillator, all configured to act as a capacitance meter.

Counting up

The block diagram of Fig.1 shows the overall scheme of things. Although the binary counter is a 12-bit type, it is only used to provide 11 digits of data to the computer. This is due to the fact that an out-of-range capacitor would cause the count to cycle back to zero and continue counting from there. The unit would then appear to give a valid reading, even though the count could have to cycle through zero several times, giving a purely arbitrary value. To avoid this, the twelfth bit is used to provide an overflow warning and halt the count if it cycles through to zero. In decimal terms, the number returned by the 11-bit counter is from 0 to 2047, making it fractionally better than a 3½-digit display, which is more than adequate for this application.

In order to take a reading, the computer must first pulse the Reset line high so that the counter starts at zero. The Trigger line is then pulsed low in order to trigger the monostable. There are five resistors available for use in the CR timing network of the monostable, and these give the unit its five measuring ranges. The capacitive section of the timing network is formed by the capacitor being tested,

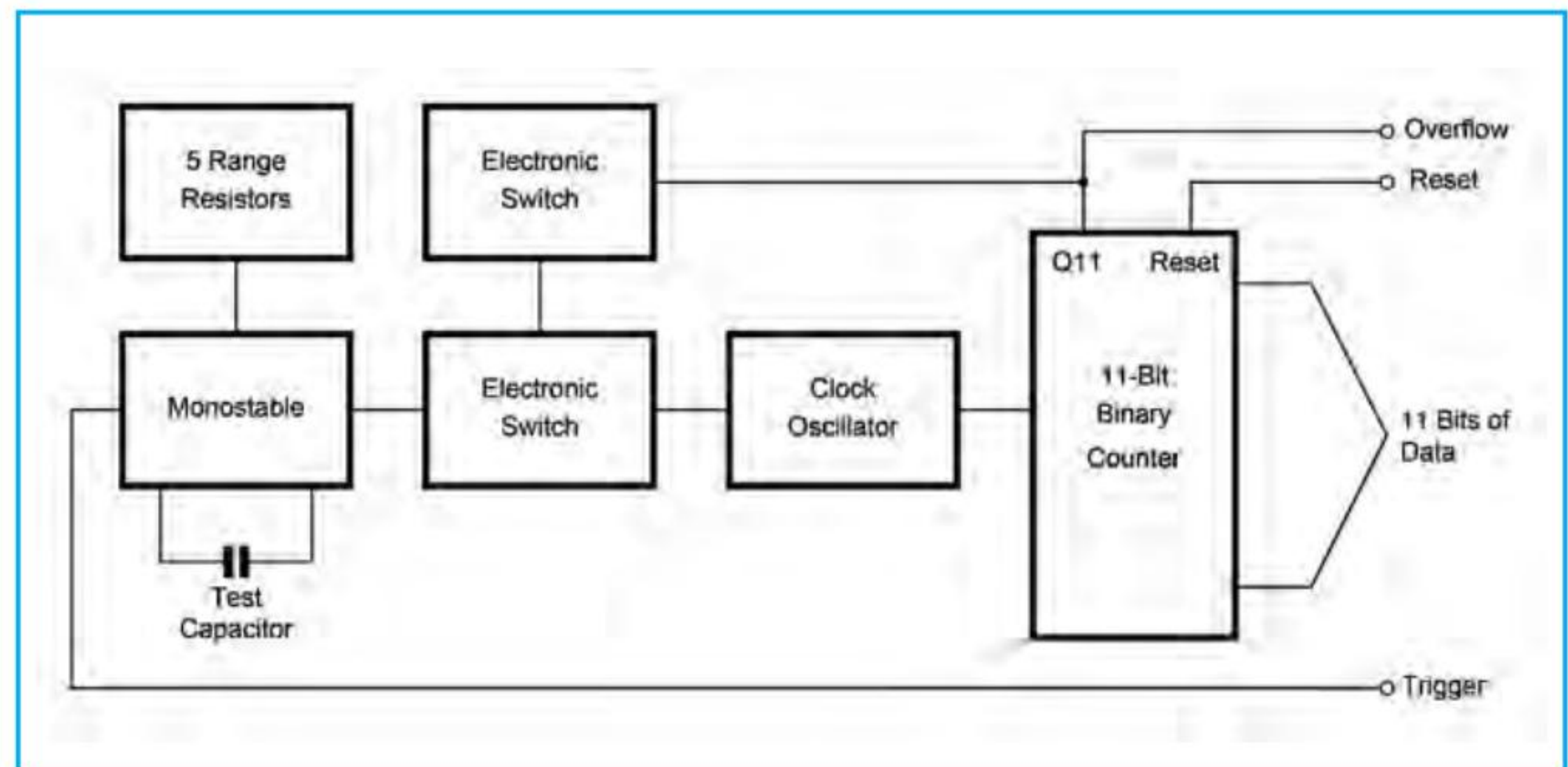


Fig.1. The general scheme of things used in the capacitance meter add-on. The binary counter is a 12-bit type, but one bit is required to provide an overflow warning

and the duration of the output pulse is proportional to its value.

The output pulse from the monostable turns on an electronic switch, and this in turn supplies power to the clock oscillator. Its output feeds the clock input of the counter, and the count therefore increases from zero for the duration of the output pulse. If output Q11 goes high, it operates a second electronic switch that blocks the first one, and deactivates the clock oscillator. This halts the count at zero. An input of the computer is used to read the logic level on Q11 and, where appropriate, an overflow warning is displayed.

Doing the math

The mathematics of the unit is reasonably straightforward. Simplifying things slightly for the moment, the monostable produces an output pulse duration of one CR seconds, and the clock oscillator operates at 100kHz. On range 2 the timing resistor is 1MΩ, and 10nF would therefore give a pulse duration of 10ms (0.01s). Since the capacitance in farads is an extremely low number, and the resistance in ohms is a very high figure, with this type of calculation it is generally better to work in megohms and microfarads. This comes out as $1 \times 0.01 = 0.01\text{s}$. (Remember, 'mega' means $\times 10^6$ and 'micro' means $\times 10^{-6}$, hence mega $\times$ micro = $10^6 \times 10^{-6} = 10^{6-6} = 10^0 = 1$).

With a 100kHz clock signal, this one hundredth of a second burst of the clock signal equates to one thousand pulses. If the test capacitance was twice as large at 20nF, the output pulse would be twice as long, and the final

value in the counter would be 2000. In other words, the reading obtained from the counter is proportional to the value of the test component. Furthermore, it is just a matter of shifting the decimal point two places to the left in order to get a reading directly in nanofarads. One slight complication is that the output pulse duration of the monostable is actually 1.1 CR seconds rather than 1 CR seconds. This does not really matter too much in practice, since it can be allowed for by reducing the clock frequency accordingly.

Circuit details

Fig.2 shows the circuit diagram for the capacitance meter add-on. IC3 is the 12-bit binary counter, and outputs Q0 to Q10 are read by inputs on the GPIO port, as in the random number generator circuit. I used a 74HC4040 for IC3, but with a clock frequency of just under 100kHz, the ordinary 4040BE CMOS version should work just as well. Pin 7 of the GPIO port (GPIO 4) is used to control the MR (master reset) input of the counter, which must be pulsed high in order to reset the counter.

The monostable uses a low-power 555 timer (IC1) in the normal monostable configuration. S1 is the Range switch, and resistors R1 to R5 give the unit its five measuring ranges, as detailed below:

Range	Resistor	Max value
1	R1	2047pF
2	R2	20.47nF
3	R3	204.7nF
4	R4	2047nF
5	R5	20.47μF

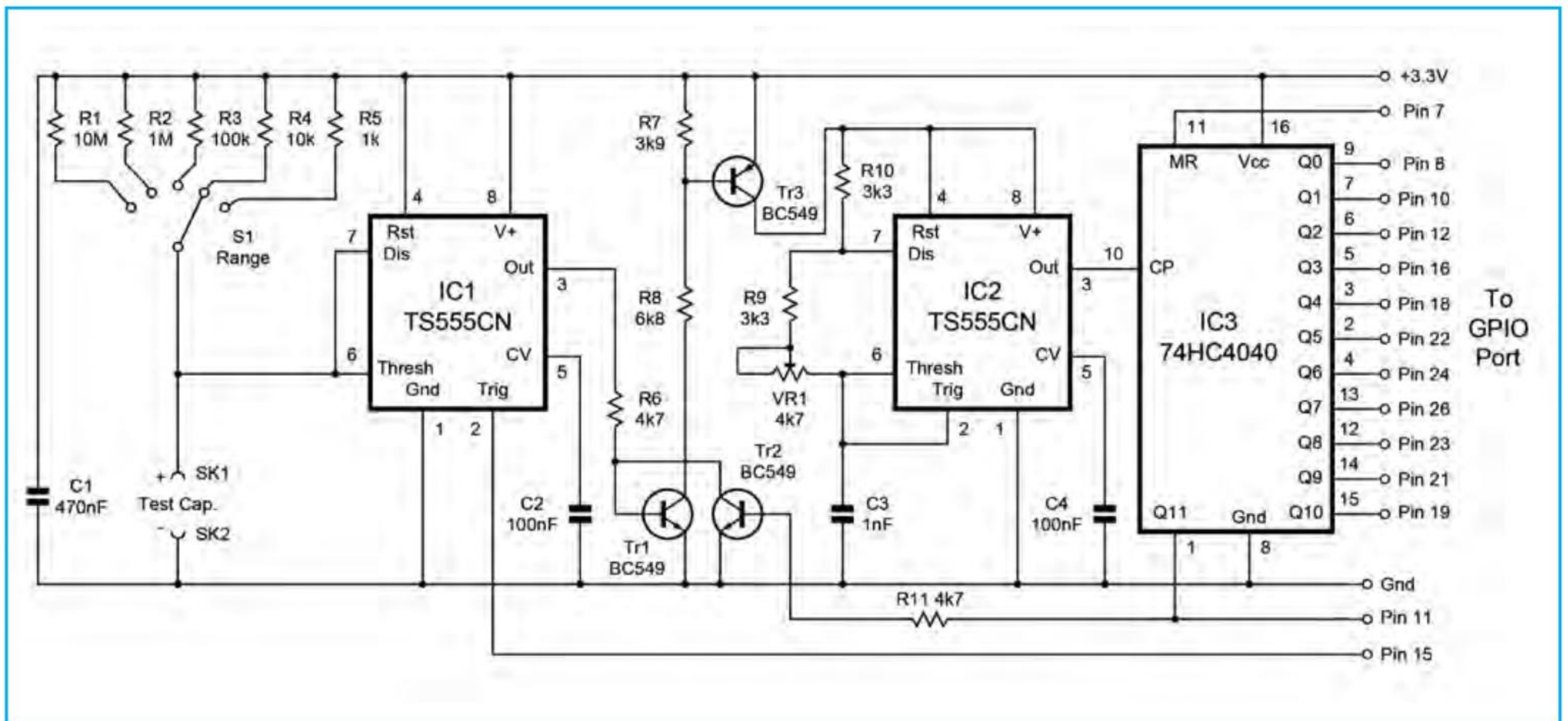


Fig.2. The circuit diagram for the capacitance meter add-on. Resistors R1 to R5 provide the unit with its five measuring ranges, with values of up to $20.47\mu\text{F}$ accommodated

Triggering of the monostable is provided by a low pulse generated on the GPIO 22 line at pin 15 of the GPIO port. The output voltage from pin 3 of IC1 was found to be inadequate to power the clock oscillator directly, and it is therefore controlled via common emitter switch Tr1, which in turn drives a second common-emitter switching transistor (Tr3). This makes it easy to block the clock oscillator when a counter overflow occurs. When Q11 of IC1 goes high, Tr2 is turned on, and it cuts off the base current to Tr1. This switches off Tr1, and therefore Tr3 and the clock oscillator as well. The GPIO 17 line at pin 11 of the GPIO port is used to monitor the Q11 output of IC3.

A hold-off is required between triggering the monostable and reading the counter, so that the count is allowed to finish before a reading is taken. This could be accomplished by using an input of the GPIO port to monitor the output of the monostable, and prevent a reading from being taken before the output returns to the low state. The simpler alternative, and the one used here, is to use a software delay to prevent premature readings of the counter.

The clock oscillator uses another low-power 555 timer (IC2) in the standard oscillator configuration. Variable resistor VR1 enables the frequency of the oscillator to be adjusted so that the unit can be calibrated. The output from this type of oscillator is rectangular, but is not a 1:1 square wave. However, practically any form of pulse waveform is adequate for a clock oscillator in an application such as this.

Components

The TS555CN specified for IC1 and IC2 is an improved version of the original NE555 timer chip. It provides

better performance than the original in several respects, such as lower current consumption and faster switching speeds. The crucial difference in the current context is that it will operate at supply potentials down to 2V. This enables the circuit to be powered from the 3.3V supply that is available on the GPIO port, which in turn enables it to interface directly to the input/output lines of the port. An ordinary NE555 has a minimum supply voltage rating of 4.5V, which means that it will not work in this circuit. Other improved versions of the 555 should be fine if they can operate at the low supply voltage used here. The improved 555 chips often use some form of MOS technology, as does the 74HC4040 used for IC3. Consequently, normal anti-static handling precautions should be observed when dealing with all three integrated circuits.

Consistent accuracy across the five ranges is dependent on resistors R1 to R5 having a suitably tight tolerance rating, which in practice means a rating of one per cent or better. A low-cost preset resistor can be used for VR1, but ideally it should be a good quality multi-turn type. This should make precise calibration a little easier, and should also give better long-term stability. A 5-way switch for S1 might be difficult to obtain, but a 6- or 12-way type with an adjustable end-stop set for 5-way operation is perfectly suitable. Tr1 and Tr2 can be any silicon NPN transistors that have reasonably high current gains. Similarly, practically any silicon PNP transistor is suitable for Tr3.

Program

The basic Python program for taking capacitance readings is provided in Listing 1. The initial

section of the program does some basic setting up and imports any modules that are required, and the next section sets up various GPIO lines as inputs or outputs, as required. In the next section, pins 7 and 15 of the GPIO port are set at the appropriate starting states. Then a reset pulse for the counter is generated on pin 7, followed by a trigger pulse for the monostable on pin 15. Next, a delay of 0.1s is provided, which is more than adequate for a reading to be taken. The maximum time taken for a valid reading to be clocked into the counter is about 0.02s.

A variable called `byte` is used to store the value read from the counter as it is built up bit-by-bit. This is set at an initial value of zero. The next section of the program reads each bit of the counter, one bit at a time. If a logic 1 level is detected, the value in `byte` is incremented by the appropriate amount for that output of the counter. The value in `byte` is otherwise left unchanged. When all eleven outputs of the counter have been read, the value in `byte` is the raw capacitance value. The rest of the program 'does the math', adding a decimal point at the appropriate position where appropriate, and printing the values for all five ranges. It is therefore just

```
>>>
Range 1 962 picofarads
Range 2 9.8 nanofarads
Range 3 98.0 nanofarads
Range 4 980 nanofarads
Range 5 9.8 microfarads
Finished
>>>
```

Fig.3. This is the reading obtained when testing a 10nF capacitor on range 2


```
>>>
Range 1 -18  picofarads
Range 2 0.0  nanofarads
Range 3 0.0  nanofarads
Range 4 0    nanofarads
Range 5 0.0  microfarads
Overflow!!!!
Finished
```

Fig.4. Measuring a 330nF capacitor on range 3 has caused the counter to overflow, and a warning message has been displayed on the screen

a matter of selecting the one for the range in use (Fig.3). A warning is printed on the screen (Fig.4) if pin 11 of the GPIO port is found to be at logic 1, indicating that the counter has cycled back to zero and a valid reading has not been obtained.

In use, a reading of '1' seems to be obtained on ranges 3, 4, and 5 when there is no test capacitor connected to the unit. On range 2 with no test capacitor the reading is usually '2', and this slight increase is probably higher due to stray capacitance and the built-in capacitance of the circuit. Things could be tidied up by reducing the displayed value by the appropriate amount, but this will not really make much difference to the accuracy of the unit.

The situation is different on range 1 where a value of about 15 to 18 is displayed when there is zero test capacitance. The exact figure will vary from one example of the circuit to another. It is definitely worth adjusting the displayed value on range 1 to account for the built-in offset of the circuit. In Listing 1 a value of 18 is deducted from the value in byte before it is displayed, but the amount deducted must be chosen to match the particular circuit in use. Doing so will greatly improve the accuracy of the unit when reading very-low-value capacitors, but readings will still only be approximations with very-low-value test components.

With a unit of this type you might occasionally find that an overflow warning is obtained, even though the capacitor has a marked value that is comfortably within the upper limit of the range in use. It could simply be that you have misread the value, and that it is actually much higher than you thought. Alternatively, the test component might be damaged and providing a short circuit. This will prevent the output of the monostable from returning to the low state, causing the counter to overflow.

Calibration

A close-tolerance capacitor is needed in order to calibrate the unit, and it should have a value of at least 30 per cent of the full-scale value of the range in use. High-value capacitors having a tolerance of one per cent or better are very expensive. Probably the best approach is to use a 10 or 15nF capacitor to calibrate the unit on range 2. Calibrating the unit is just a matter of using a bit of trial and error to adjust VR1 for good accuracy. Readings are very stable, and this design is certainly better in this respect than the ultra-simple one featured previously.

Listing 1

```
import RPi.GPIO as GPIO
import time
GPIO.setmode(GPIO.BOARD)
GPIO.setwarnings(False)

GPIO.setup(11, GPIO.IN)
GPIO.setup(8, GPIO.IN)
GPIO.setup(10, GPIO.IN)
GPIO.setup(12, GPIO.IN)
GPIO.setup(16, GPIO.IN)
GPIO.setup(18, GPIO.IN)
GPIO.setup(22, GPIO.IN)
GPIO.setup(24, GPIO.IN)
GPIO.setup(26, GPIO.IN)
GPIO.setup(23, GPIO.IN)
GPIO.setup(21, GPIO.IN)
GPIO.setup(19, GPIO.IN)
GPIO.setup(7, GPIO.OUT)
GPIO.setup(15, GPIO.OUT)

GPIO.output(15, True)
GPIO.output(7, False)
GPIO.output(7, True)
GPIO.output(7, False)
GPIO.output(15, False)
GPIO.output(15, True)
time.sleep(0.1)
byte = 0

if GPIO.input(8):
    byte = byte + 1
if GPIO.input(10):
    byte = byte + 2
if GPIO.input(12):
    byte = byte + 4
if GPIO.input(16):
    byte = byte + 8
if GPIO.input(18):
    byte = byte + 16
if GPIO.input(22):
    byte = byte + 32
if GPIO.input(24):
    byte = byte + 64
if GPIO.input(26):
    byte = byte + 128
if GPIO.input(23):
    byte = byte + 256
if GPIO.input(21):
    byte = byte + 512
if GPIO.input(19):
    byte = byte + 1024

print ("Range 1", byte-18, " picofarads")
print ("Range 2", byte/100, " nanofarads")
print ("Range 3", byte/10, " nanofarads")
print ("Range 4", byte, " nanofarads")
print ("Range 5", byte/100, " microfarads")
if GPIO.input(11):
    print ("Overflow!!!!")

GPIO.cleanup()
print ("Finished")
```

It should be possible to develop the system a bit further. Using the extra lines available on the 40-pin version of the GPIO port it would be possible to control the range from the computer. Any form of electronic switching would almost certainly impair the accuracy of the unit, and the old fashioned method of using relays or reed relays would be better. It would then be possible to implement auto-ranging. A reading would be taken on range 1, and if it was in-range it would be displayed. If not, a reading would be taken on range 2, and it would be displayed if it was in-range. Otherwise a reading would be taken on range 3, and so on, until a valid reading was obtained and displayed.

Ammeters and voltmeters

FREQUENT *EPE Chat Zone* contributor **grahamrounce** posted a question about meters: 'I have a 30,000 ohms/volt moving coil meter, and seem to have forgotten how to work out its resistance on say the 100 μ A range, or come to that, any current or voltage range. Could someone please remind me? And a digital meter? – there doesn't seem to be any equivalent parameter quoted. Thank you.'

As is often the case, fellow *Chat Zone* users provided some answers (particularly **bruce** in this case). We will look at the topic in some depth and take the opportunity to review some of the circuit theory (and resulting practicalities) associated with using meters and designing related measurement circuits. Since the question mentions digital meters we will start with a general comparison between analogue and digital meters, and then look at the moving coil meters and more generally at the effect using a meter has on the circuit under test. Finally, we will address the specific points in the post.

Analogue vs digital

In an age of cheap digital technology, one thought which may occur immediately after reading **grahamrounce's** post is, why bother with an analogue meter? Of course, the answer may be that you already own a moving meter and want

to make use of it rather than buying something new. Another possibility is aesthetics – analogue meters provide a retro or vintage look, if that is what you are after.

In terms of multimeters (see Fig.1 and Fig.2 for examples) we can make some specific comparisons. Low-cost analogue multimeters are readily available at similar costs to low-cost digital meters. Higher up the quality scale there is less choice in analogue meters, but a few are available. Digital multimeters are generally more accurate than analogue ones, they are more versatile, have more features and functions, and commonly provide measurement of a wider range of quantities. Some have advanced capabilities, such as data logging or trend graphing and transfer of data to computers.

The numerical value of the measurement is usually easier to read from a digital meter and the display may well tell you directly if the reading is in, for example, mV or V, having automatically selected the range. Of course, digital multimeters may also provide manual range setting for when that is more convenient, further highlighting their versatility. On analogue multimeters you will have to set the range manually and interpret the reading accordingly. Furthermore, there will typically be several scales on an analogue multimeter (see Fig.1),

so you have to make sure you read the right one – a potential source of error and confusion, particularly on small, cheap multimeters where the scales may not be very easy to read.

Analogue meters have an advantage over digital meters in that they can provide a more intuitive view of fluctuating measurements – the needle moves in sympathy with the measured voltage or current. Events such as peaks in the measured value show up when the needle moves sharply, but might be missed when reading a digital multimeter, which is averaging and updating more slowly. The changing lower order numbers on a digital display will usually be much harder to interpret – in particular, its behaviour is dominated by the update rate of the display. Naturally, electro-mechanical analogue meters, such as moving coil meters, are not infinitely fast, so will not respond to very short peaks. The dynamics of analogue meters may be (or would have been) an important part of a specification in some applications.

This drawback of digital readouts can be overcome by also providing an 'analogue' representation of the signal on the display (see Fig.3). Typically this is a bar graph, which updates more rapidly than the numerical reading, but full graphical on-screen representations of analogue meters are of course possible. Digital multimeters may also provide min/max/average reading over a period, which means you do not need to watch for the needle to 'jump' to detect a peak. Such a digital meter will also measure the peak rather than just telling you 'something happened', and may be able to capture events too fast to kick a needle. Despite this, an analogue meter may still have the advantage in



Fig.1. Analogue Multimeter



Fig.2. Digital Multimeter



Fig.3. Digital multimeter with 'analogue' bar graph

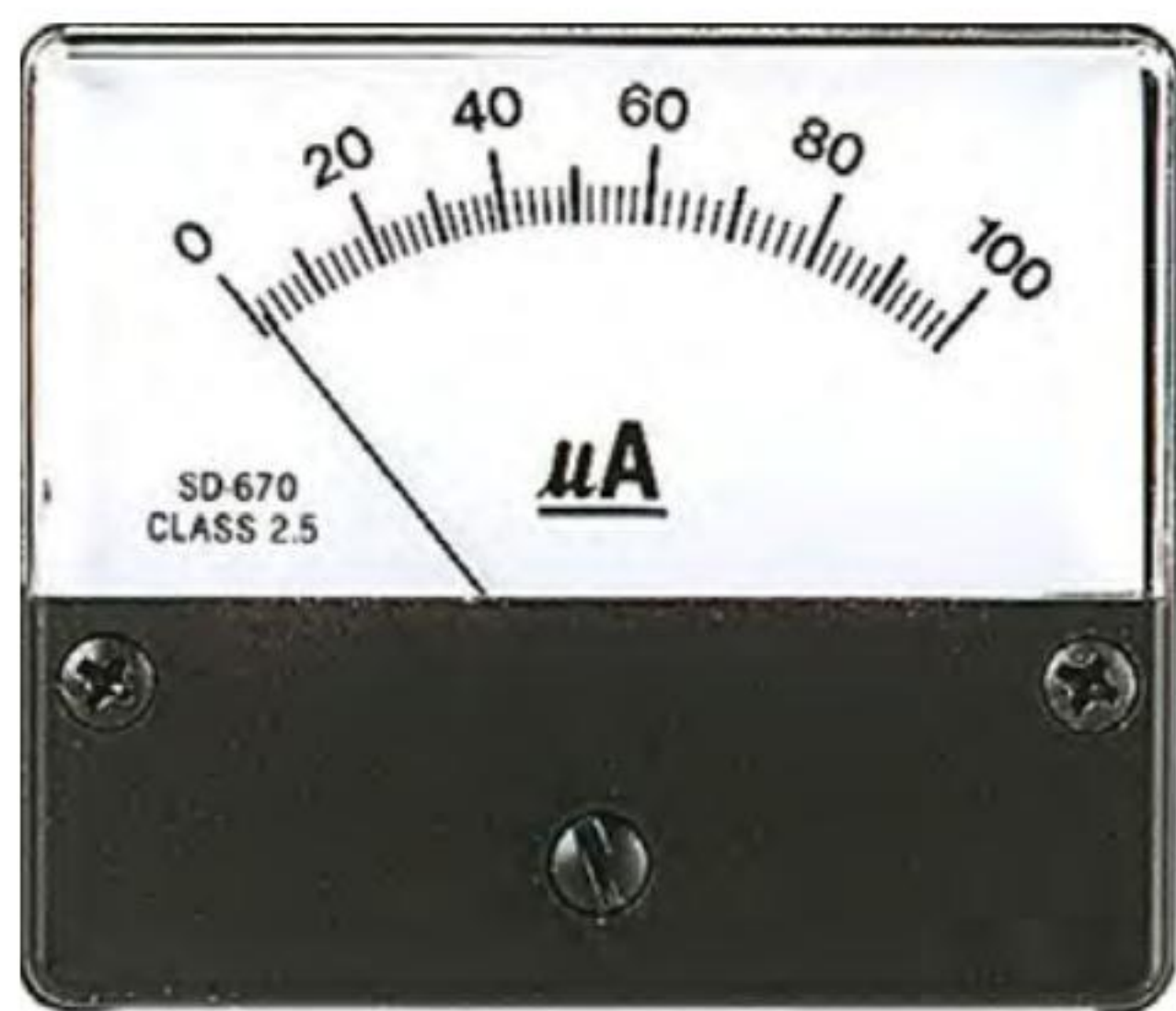


Fig.4. Moving coil panel meter

some situations – for example, where the users wants to keep an eye on a meter using their peripheral vision, where a moving meter needle will be easier to monitor than, say, an LCD screen with possible viewing angle limitations.

Moving coil

The moving coil meter is an important part of the history of our understanding of electricity. Its operation is based on the fundamentals of interaction between electricity and magnetism, which were developed in the early 19th century by scientists such as Hans Christian Ørsted, André-Marie Ampère and Michael Faraday. In 1882, Jacques-Arsène d'Arsonval and Marcel Deprez developed a basic form of moving coil meter, which provided better linearity and lower sensitivity to magnetic materials in its environment than earlier moving magnet meters. The design of moving coil meters was further improved by Edward Weston in 1888, who created the design which still forms the basis of modern moving coil meters. As metering technology improved it led to further advances in our understanding of electricity and magnetism, and these improved measurements led to new discoveries or proof of theories.

A typical moving coil panel meter is shown in Fig.4. A moving coil meter comprises a coil of wire round an iron core placed between the poles of a permanent magnet (see Fig.5). When direct current flows through the coil a force is produced on the coil – this is same effect as used in electric motors. The current in the coil creates a magnetic field – it acts as an electromagnet with the iron core concentrating the magnetic field. The magnetic field from the coil repels or attracts the magnetic field of the permanent magnet and produces a force that causes the coil to rotate. This force is opposed by spiral springs attached to the coil, which can also act as the conductors to supply the current to the coil. The coil is often mounted (via spindles) on bearings, which allow easy movement. With correctly shaped magnet poles and good mechanical design the rotation of the coil has a good linear relationship with the applied current.

The meter's needle (pointer) is mounted on the coil so that it rotates with it. A long needle means that only a small amount of coil movement produces a large pointer deflection. There is usually a small screw head on the needle mounting so that the needle can be rotated with respect to the coil. This is in order to set the position of the needle with no current flowing to accurately match the zero point on the meter's scale. The coil responds to direct current in either direction with the rotation occurring in opposite directions for opposite current flow. This means that centre-zero meters can be made, although when moving coil meters are used in analogue multimeters the zero is on the left hand side.

Although fuses and other techniques should protect all multimeters from damage by excessive current flow, analogue multimeters based on moving coil meters are more fragile than digital meters due to their more delicate mechanical structure.

Back to basics

Before discussing meter properties and circuits we will quickly review some basic circuit theory which we will need to fully appreciate their operation and limitations. First, the well-known circuit theorem called Ohm's law (see Fig.6), which states the relationship between the resistance of a resistor, R (measured in ohms), the voltage across the resistor, V (measured in volts), and the current through it, I (measured in amps). This can be written in three forms, so that if you know two of these quantities you can find the other.

$$V = IR \quad I = V/R \quad R = V/I$$

By 'resistor', we can mean anything that behaves like a resistor, which includes the coil of a moving coil meter with a direct current flowing through it.

Ohm's law provides the relationship between current and voltage for a given resistor. Other important laws describe the relationships between voltages in a circuit (irrespective of current values)

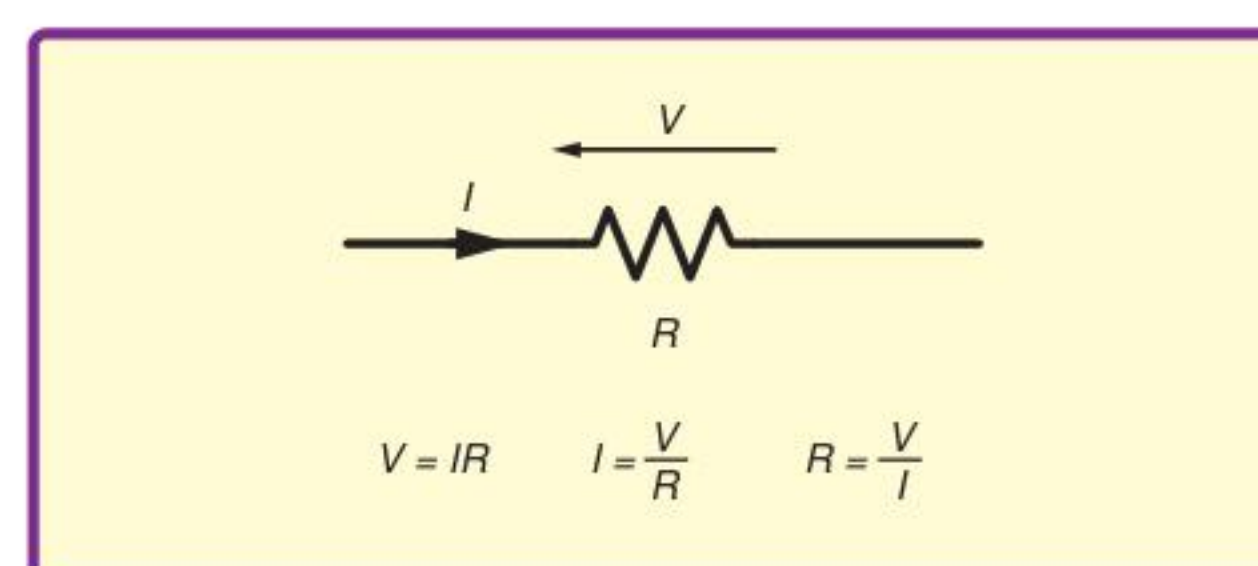


Fig.6. Ohm's law: the relationship between resistance, voltage and current

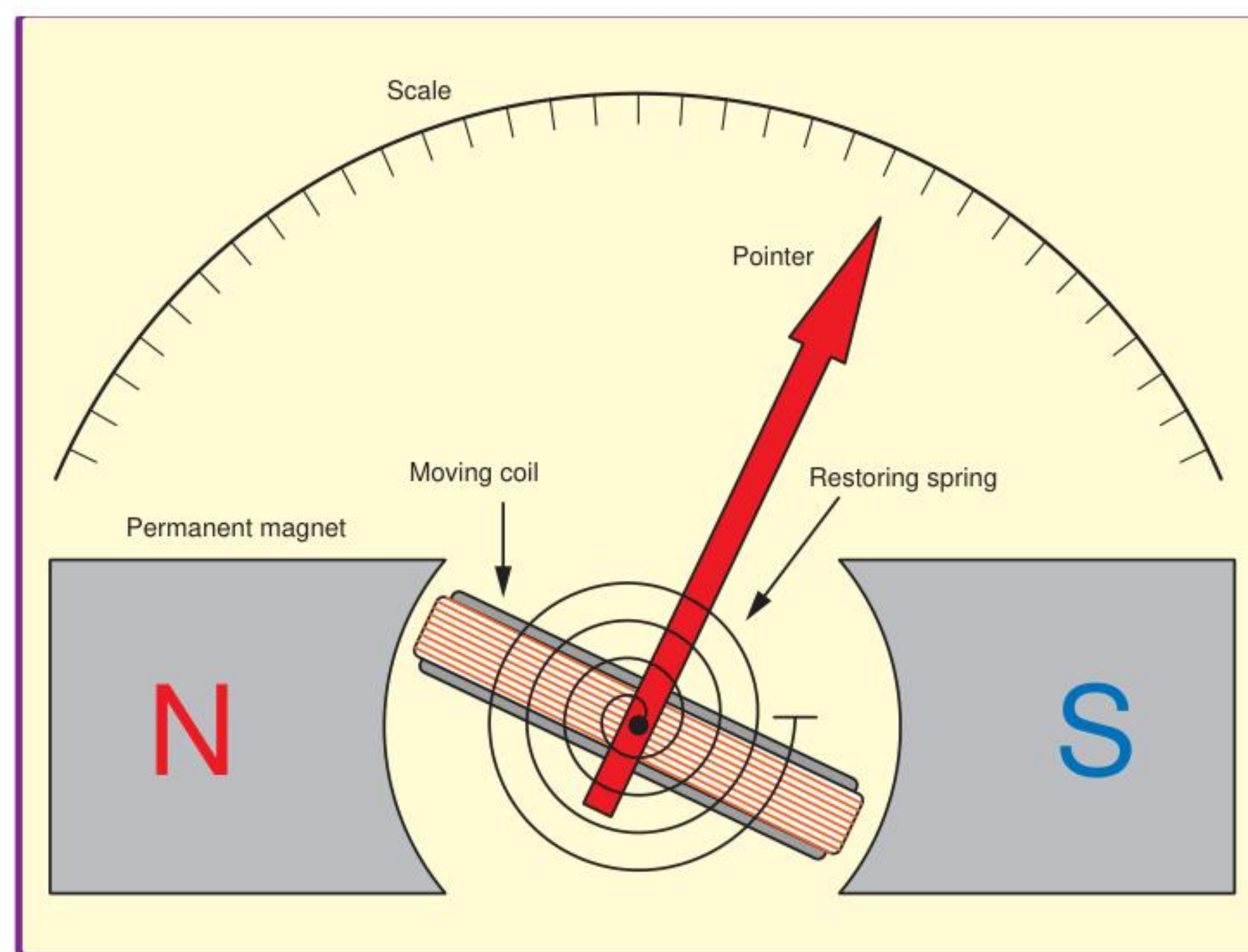


Fig.5. Structure of a moving coil meter

and between currents in a circuit (irrespective of voltage values). Here we have Kirchhoff's two laws (the voltage law and the current law).

Kirchhoff's voltage law (KVL) can be stated as:

Taking direction into account, the sum of voltages around a loop in a circuit is equal to zero.

The direction of the voltage of a voltage source, or the voltage dropped across a component is taken as being from the negative end towards the positive end. In forming the KVL sum an individual voltage is positive if its direction is the same as the loop direction and negative otherwise. We can loop the other way round, the law still works; just reverse all the signs in the sum.

An example of KVL is shown in Fig.7. The voltage source has a positive direction and voltage drops across the resistor are opposite to the loop direction. Here, the voltages sum to zero – alternatively, we can say that the sum of the voltages across the resistors equals the voltage of the source. We have:

$$V_{S1} - V_{R1} - V_{R1} = 0$$

$$V_{S1} = V_{R1} + V_{R1}$$

Kirchhoff's current law (KCL) can be stated as:

Taking direction into account, the sum of currents at a junction in a circuit is zero.

Currents flowing into the junction

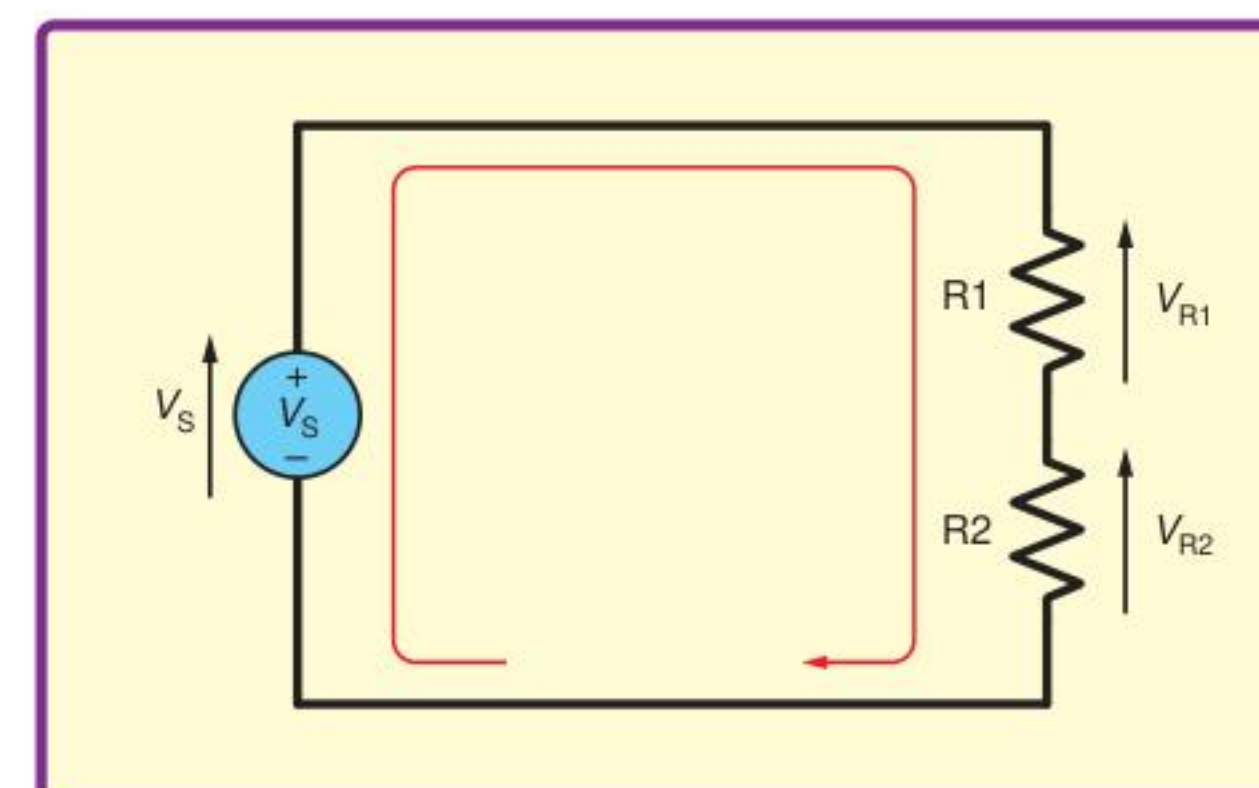


Fig.7. Kirchhoff's voltage law

are positive and currents flowing out are negative (again, if we swap this the law holds but all the signs in the sum change). An example is shown in Fig.8. The sum of the currents is zero – alternatively, we can say the two currents flowing out add up to the current flowing in.

$$I_{R1} - I_{R2} - I_{R3} = 0$$

$$I_{R1} = I_{R2} + I_{R3}$$

Current meter

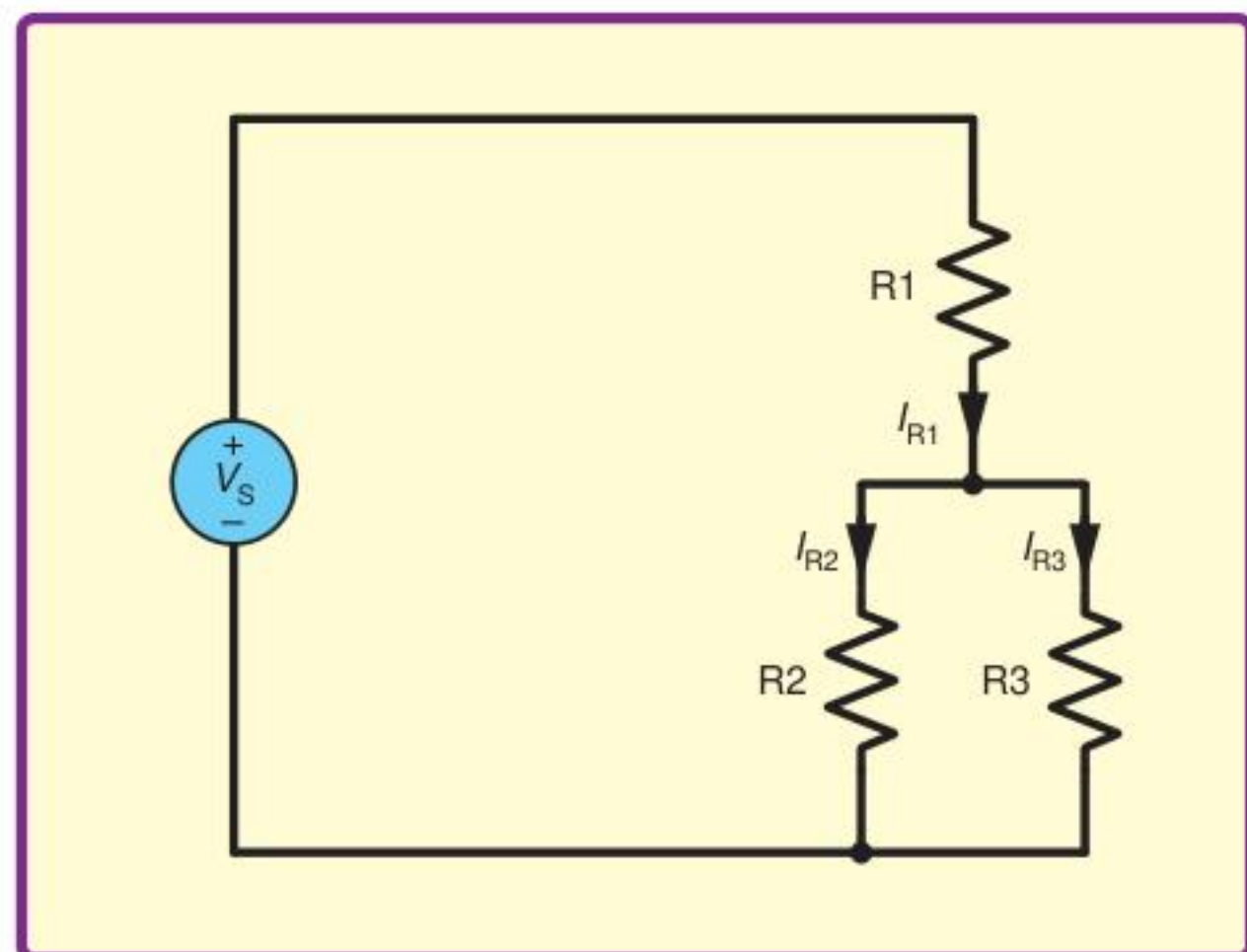


Fig.8. Kirchhoff's current law

As indicated by the earlier discussion a moving coil meter fundamentally responds to the current flowing in the coil – that is, it is naturally acts an ammeter. A particular moving coil meter will have a certain current corresponding to the maximum amount of movement – when the pointer is at the end of the scale. This is known as the ‘full-scale deflection’ (FSD) current. Typical FSD currents range from around 20μA to several milliamps. The minimum current which can be measured is set by the FSD and to some extent the length of the needle and size of the scale, which taken together determine the smallest change in current which can be readily observed.

An ideal ammeter has zero resistance, but real meters have some resistance. For moving coil meters this can be quite significant and typically ranges from a few hundred ohms to a few kilohms. This means that inserting an ammeter into a circuit to make a measurement will disrupt the voltages and currents in the circuit being measured to some extent. In particular, an ideal ammeter would have zero voltage across it, but a real ammeter will have a voltage across it when making a measurement, this is called the voltage burden.

Fig.9 illustrates the impact of inserting an ammeter into a circuit. Here we have an ideal voltage source, V_S , connected to a load resistance R_L (see Fig.9(a)). We want to measure the current in the load, I , so we insert an ammeter. If the ammeter is ideal (as in Fig.9(b)) nothing will change and the ammeter will read the original value of load current. If we insert a real ammeter with resistance R_M then there will be a voltage across that ammeter, the voltage burden – V_{Burden} , given by Ohm's law as IR_M . Since the

voltage source has not changed, KVL tells us that the voltage across the load must now be smaller.

For the example in Fig.9, if V_S is 10V and R_L is 100kΩ then the current in the original circuit will be 100μA ($= 10V/100k\Omega$). This is the current that will be measured by an ideal ammeter. If we insert an ammeter with resistance 1kΩ (this could be a moving coil meter with 100μA FSD) then the total resistance is 101kΩ and the current will reduce to 99μA. The voltage burden will be 100mV ($= 100\mu A \times 1k\Omega$). Inserting the ammeter has caused the current to change by about 1%, which in many cases would be acceptable, particularly as the accuracy of typical moving coil panel meters is of this order.

For the example in Fig.9, if $V_S = 0.1V$ and $R_L = 1k\Omega$ then the current in the original circuit will be 100μA ($= 0.1V/1k\Omega$) as in the previous example. Again, this is the current that will be measured by an ideal ammeter. If we insert the same ammeter, with resistance 1kΩ, then the total resistance equals 2kΩ and the current will reduce to 50μA. The voltage burden will be 50mV ($= 100\mu A \times 1k\Omega$). Inserting the ammeter has caused the current to change by 50%, which is unlikely to be acceptable as a measurement of the load current.

The preceding examples illustrate that making a current measurement by inserting an ammeter may result in significant errors. In particular, it is situations where the source voltage is low which are likely to cause problems when using ammeters with relatively high resistance. In such situations, moving coil meters may not be appropriate, although this issue affects all ammeters (analogue and digital) inserted into a circuit to some extent. In more demanding cases, measurements can be made by active electronic circuits which can amplify the voltage across a much smaller resistance, or provide a virtual earth with very low voltage.

Shunts

We can use an ammeter to measure currents higher than the FSD by using a resistor, called a ‘shunt’, in parallel

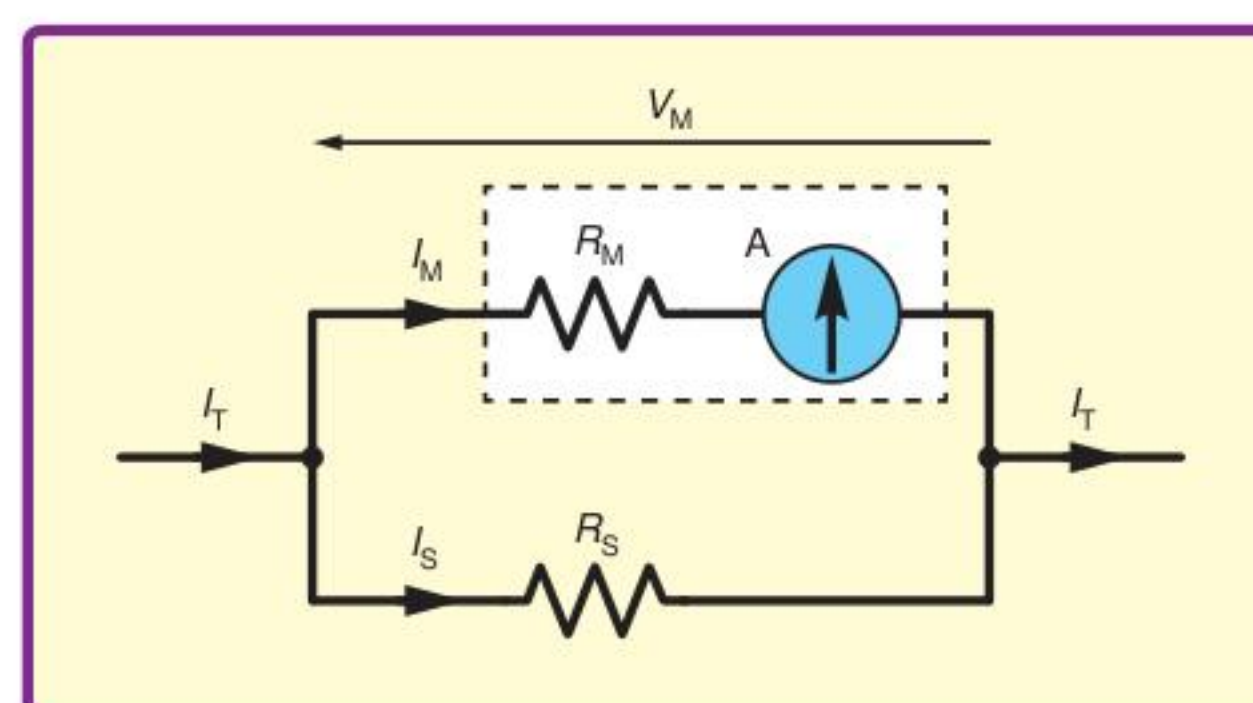


Fig.10. Ammeter with shunt

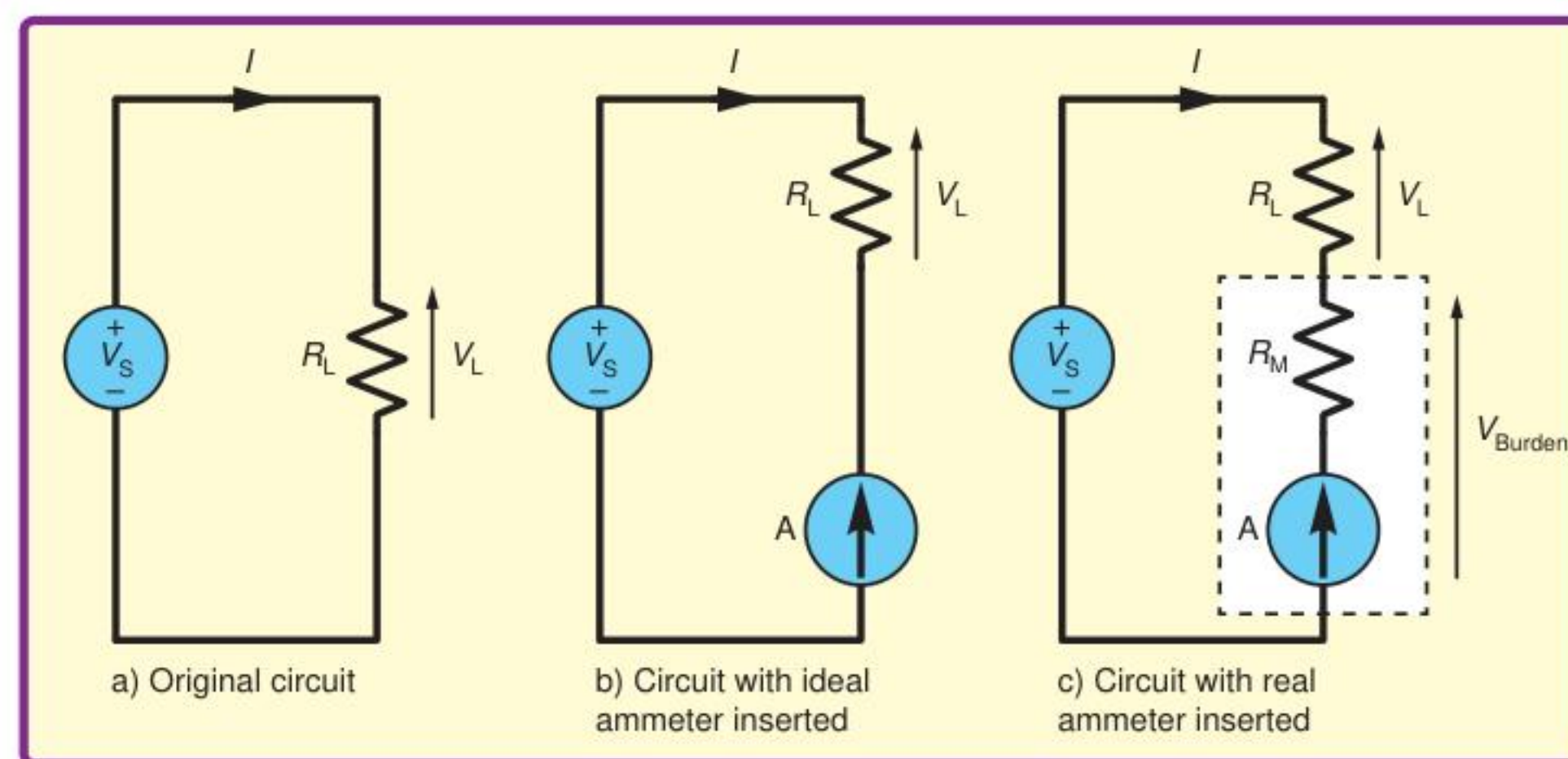


Fig.9. Effect of an ammeter on a circuit

with the meter. Fig.10 shows an ammeter with a shunt in which the total current (I_T) is the current we want to measure. I_T splits between the meter current (I_M) and the shunt current (I_S) in accordance with KCL. KVL tells us that the voltage across the meter and the shunt are the same (labelled V_M in Fig.10). Using Ohm's law we can write:

$$V_M = I_M R_M$$

And

$$V_M = I_S R_S$$

Combining these we get:

$$I_S R_S = I_M R_M$$

Which can rearrange to give the required value of the shunt resistance:

$$R_S = I_M R_M / I_S$$

We use the FSD case, so I_M is the meter FSD. We know R_M , the meter resistance, but not I_S , the shunt current. However KCL tells us:

$$I_S = I_T - I_M$$

In which I_T is the full-scale current of the meter with the shunt. Substituting this into the previous equation we get: As an example, consider an ammeter

$$R_S = \frac{I_M R_M}{(I_T - I_M)}$$

with an FSD current of 100μA and resistance of 1kΩ. If we would like to measure currents up to 10mA, then the shunt we require is:

In multimeters, a switch is used to

$$R_S = \frac{100\mu \times 1k}{(10m - 100\mu)} = 10.1\Omega$$

change the shunt resistance to provide different current ranges. Care must be taken with the switch design to prevent large currents damaging the meter during range changes. For example, imagine a current of 900mA was being measured on a 10A range and the user switched to the 1A range. If the switch went open circuit as it was moved (disconnecting all the shunts), then the full 900mA would pass through the meter. If this was, say, a 100μA FSD

moving coil meter it would probably be damaged. To prevent this, range selection switches must be *make-before-break*. An alternative approach to switching individual shunt resistors in parallel is to have a chain of resistors across the meter and select different tap points. This is called an Ayrton shunt and was mentioned by **rob_guyer** in the discussion on **grahamrounce's** post.

Voltmeter

As we have already discussed, a moving coil meter has a fixed resistance and therefore a certain voltage across it at FSD current. If we apply a voltage at, or lower than this, to the meter the deflection will be proportional to the voltage. Thus, a moving coil meter can be used as a voltmeter as well as an ammeter.

We saw that inserting an ammeter in a circuit to measure current changed the currents and voltages in the circuit, leading to errors. Likewise, if we connect a voltmeter across a component to measure the voltage some current will be diverted into the meter, again changing the situation in the circuit resulting in an imperfect measurement. Whereas ammeters ideally have zero resistance voltmeters ideally have infinite resistance.

Fig.11 illustrates the impact of attaching a voltmeter to a circuit. Here we want to measure the open-circuit output voltage of a device or circuit. As with any such situation we can represent this as an ideal voltage source (V_S) in series with a source resistance (eg, the output resistance of an amplifier, or internal resistance of a battery) – see Fig.11(a). The same representation can be applied to a voltage measurement anywhere in a circuit (it does not have to be at a designated output).

If we attach an ideal voltmeter to the circuit in Fig.11(a), as shown in Fig.11(b), nothing will change. The ideal voltmeter has infinite resistance and will therefore not cause any current to flow. The meter will measure V_O correctly. However, if we attach a real voltmeter the situation will be as shown in Fig.11(c). The finite meter resistance (R_M) will cause a current (I_M) to flow from the source. This in turn will cause a voltage drop across the source resistance given by Ohm's law as:

$$V_R = I_M R_S$$

The voltage measured will be V_R lower than the actual voltage, that is:

$$V_M = V_O - I_M R_S$$

This problem is referred to as the voltmeter loading effect. As with errors caused by ammeters, voltmeter loading may be minimal or so severe that the measurement is useless. It all depends on the relative value of R_S and R_M . The meter resistance must be much higher than the source resistance to get a valid measurement. Circuits with very high resistances are therefore the most difficult to deal with and again moving coil meters will not be usable in more challenging cases. Active circuits can be used to build higher performance voltmeters, for example using a high input impedance op amp to buffer the voltage being measured.

Multipliers

We noted that a moving coil meter will have a natural full-scale voltage related to the FSD current and meter resistance. As with current measurement this, together with the scale size, will limit the smallest voltage which can be measured. Just as we can measure higher currents using a shunt we can also add resistors to increase the voltage range of a meter. This time we put resistors in series with the meter and they are referred to as multipliers.

Fig.12 shows a meter with a multiplier resistor, R_U . The meter is an ammeter with full scale current I_M and resistance R_M . We want a full scale voltage of V_M and KVL tells us that this will be equal to the sum of the voltages across the two resistors, these in turn are given by Ohm's law in terms of the meter current and resistance values. So we have:

$$V_M = I_M R_M + I_M R_U$$

So

$$I_M R_U = V_M - I_M R_M$$

Giving the required multiplier as:

$$\text{For example, consider an ammeter}$$

$$R_U = \frac{(V_M - I_M R_M)}{I_M}$$

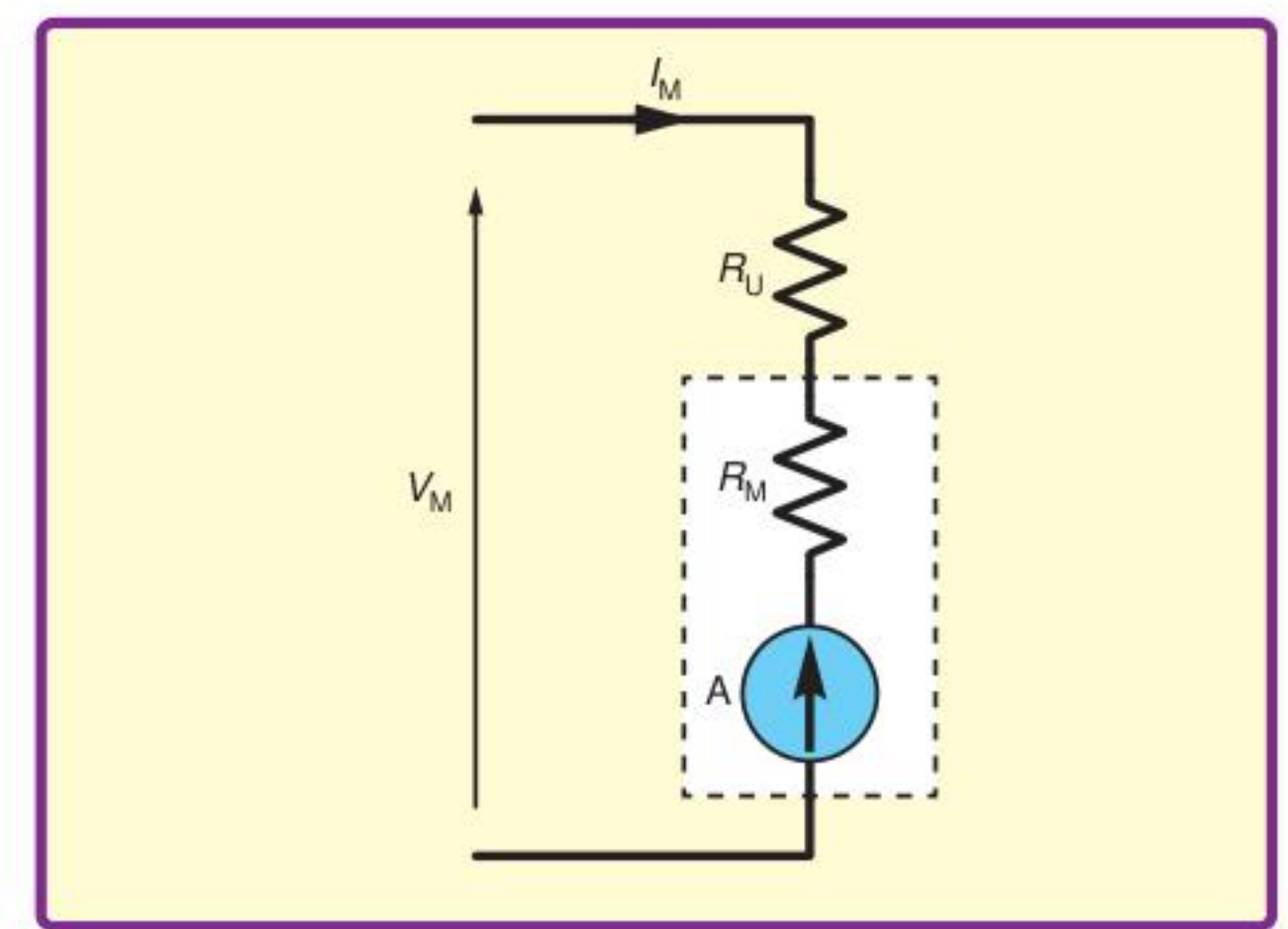


Fig.12. Multiplier resistor to use an ammeter to measure voltage

with an FSD current of $100\mu\text{A}$ and resistance of $1\text{k}\Omega$. If we would like to measure voltages up to 10V , then the multiplier we require is:

In a multimeter a switch can be used

$$R_S = \frac{(10 - 100\mu \times 1\text{k})}{100\mu} = 99\text{ k}\Omega$$

to select various multiplier resistors to set different voltage ranges. If very high voltages are being measured then it is usual to implement the multiplier resistor as a set of resistors in series, whose value adds up to the required multiplier value. This reduces the voltage across each individual resistor and reduces the possibility of breakdown due to the high voltage.

Sensitivity

Whatever multiplier is used a moving coil voltmeter will require the same current at full-scale voltage – this will be the FSD current of the meter. The lower this is the less loading will occur. This brings us to **grahamrounce's** original question. The 'ohm/volt' specification of a moving coil meter is called its sensitivity. If we look at Ohm's law we see ohm/volt corresponds to R/V , which is $1/I$ (the reciprocal of current). Thus, the sensitivity of a meter is simply one divided by the FSD current. For the $100\mu\text{A}$ FSD example we have been using, the sensitivity is $1/100\mu\text{A} = 10\text{k}\Omega/\text{V}$.

The sensitivity does not tell you the meter's coil resistance; that is a separate specification. For a multimeter made using a moving coil ammeter, the sensitivity will tell you the resistance of the meter on each range. Multiply the full-scale voltage by the sensitivity to find the resistance, which will tell you the conditions under which the meter can be used without causing too much loading (the source resistance must be much higher). For example $10\text{k}\Omega/\text{V}$ on a 10V range is $100\text{k}\Omega$ (corresponding exactly with the example above where we have a $99\text{k}\Omega$ multiplier plus a $1\text{k}\Omega$ meter resistance). Digital voltmeters (and the voltage ranges of digital multimeters) are not specified in the same way because they usually have the same resistance across all voltage ranges and, which is often $10\text{M}\Omega$.

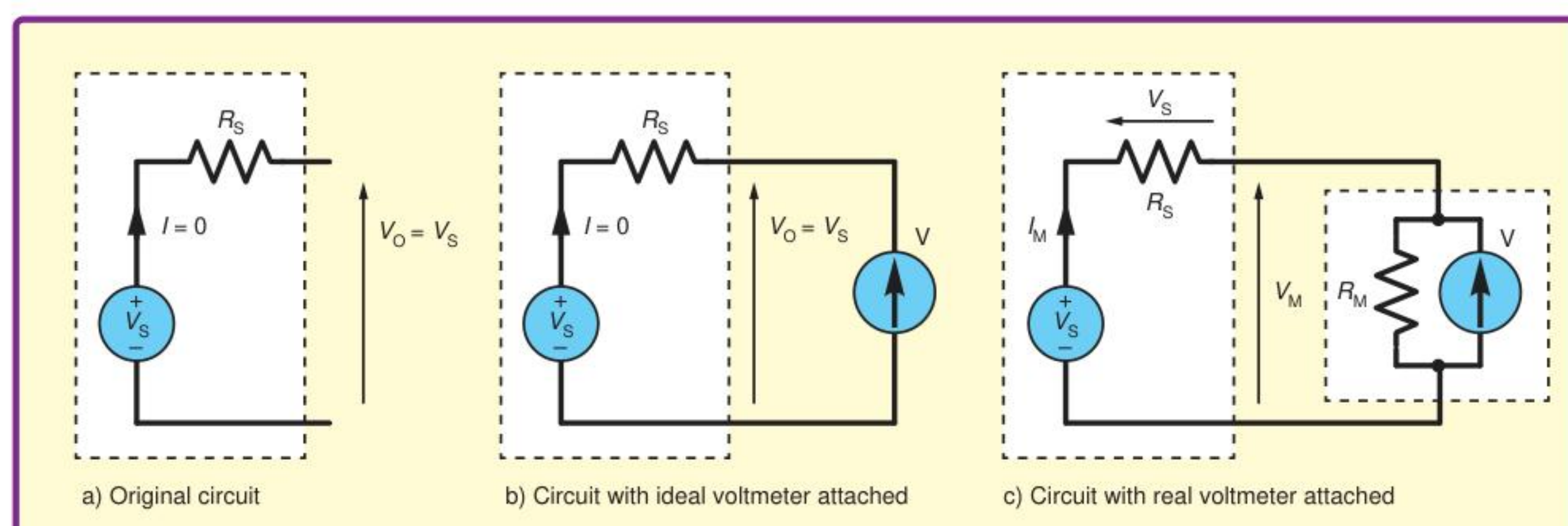
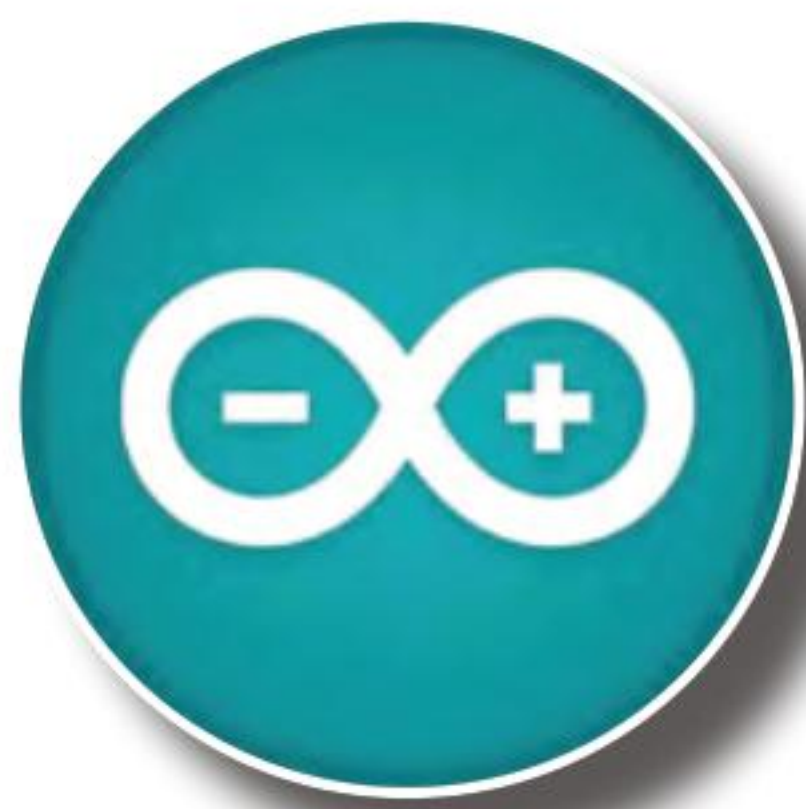


Fig.11. Effect of a voltmeter on a circuit

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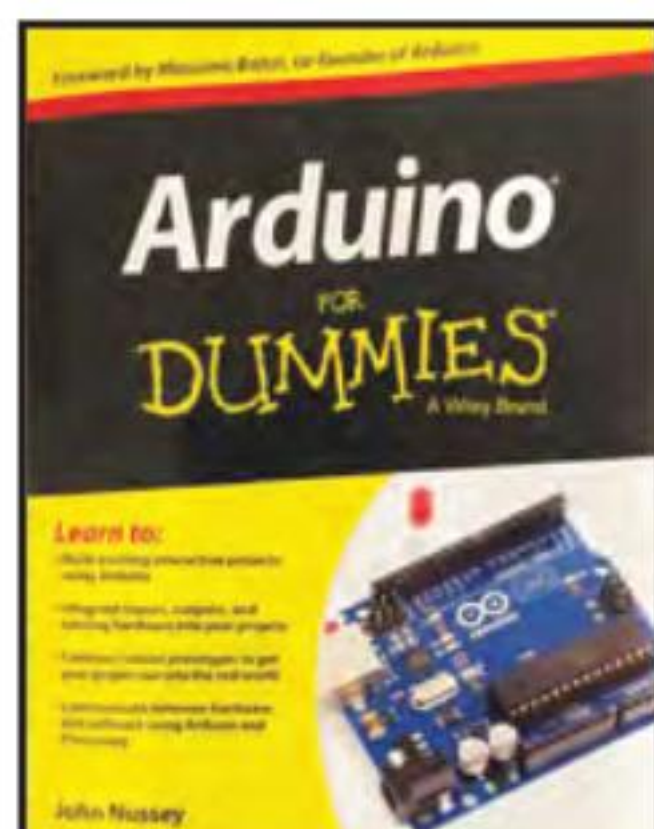
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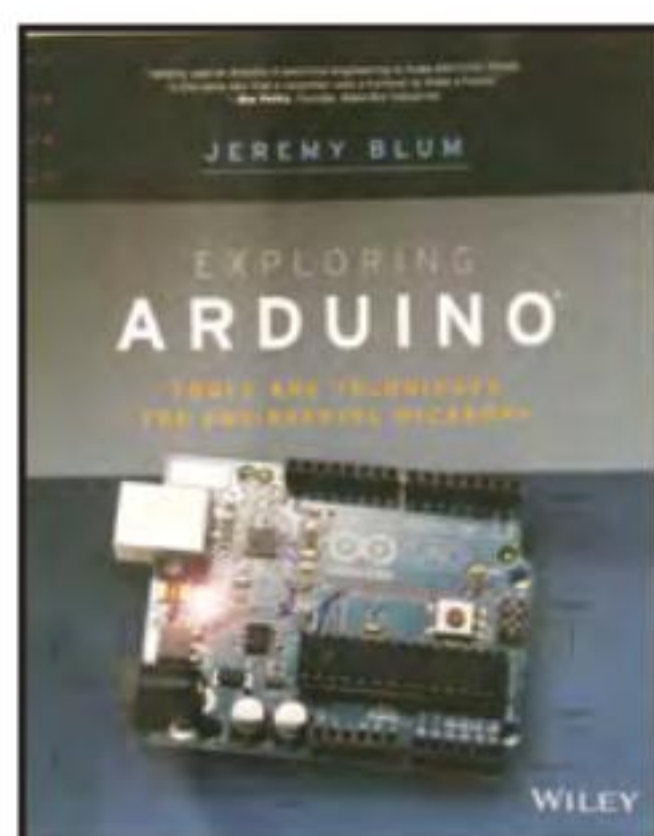
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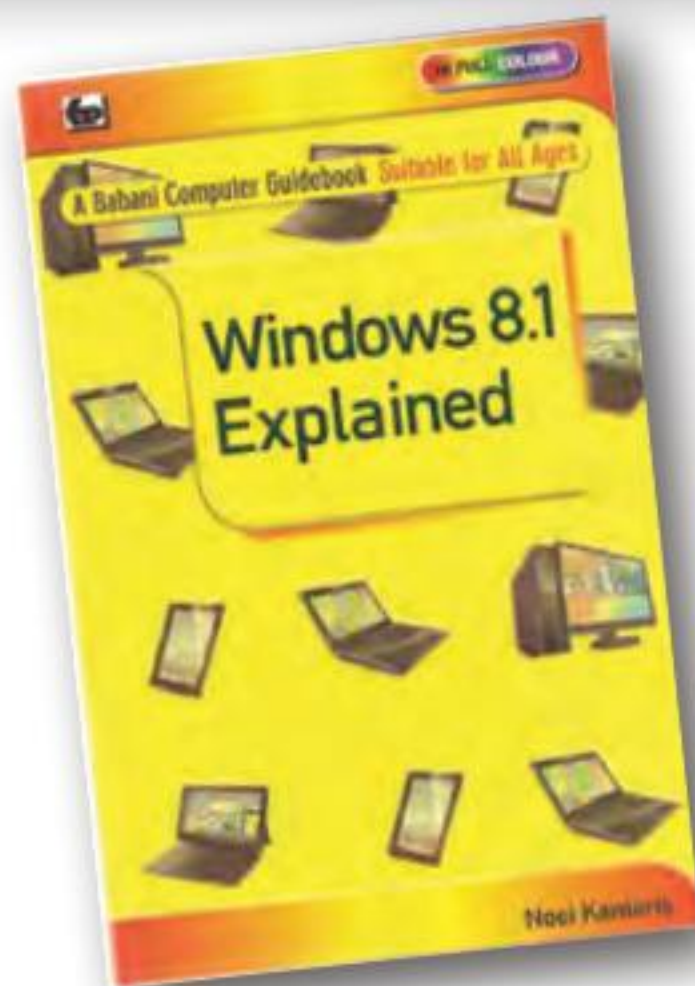
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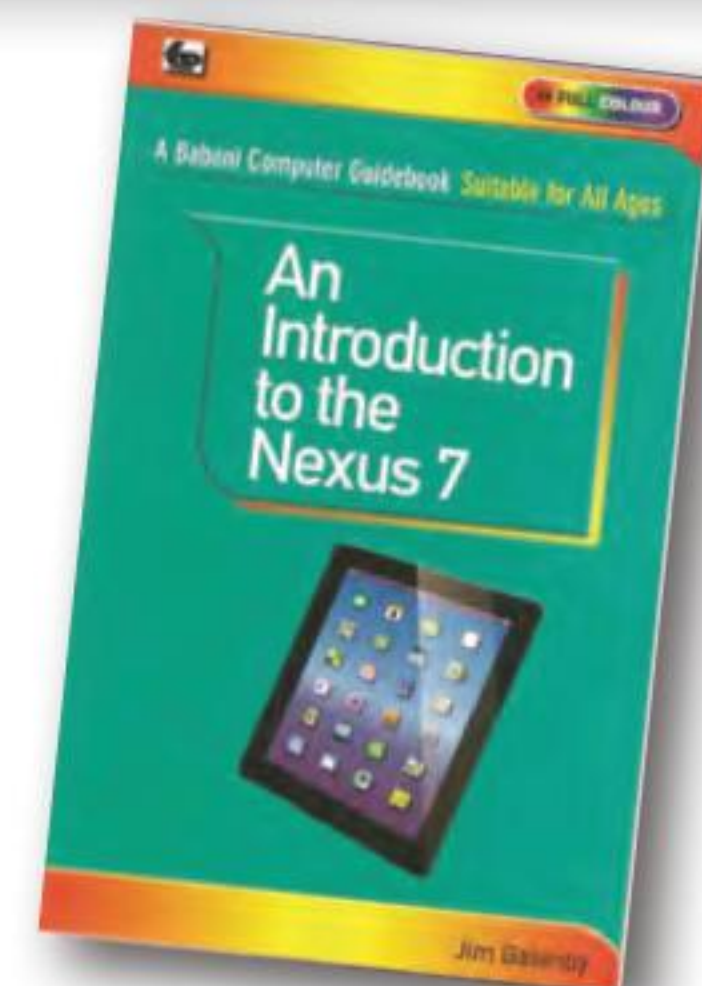
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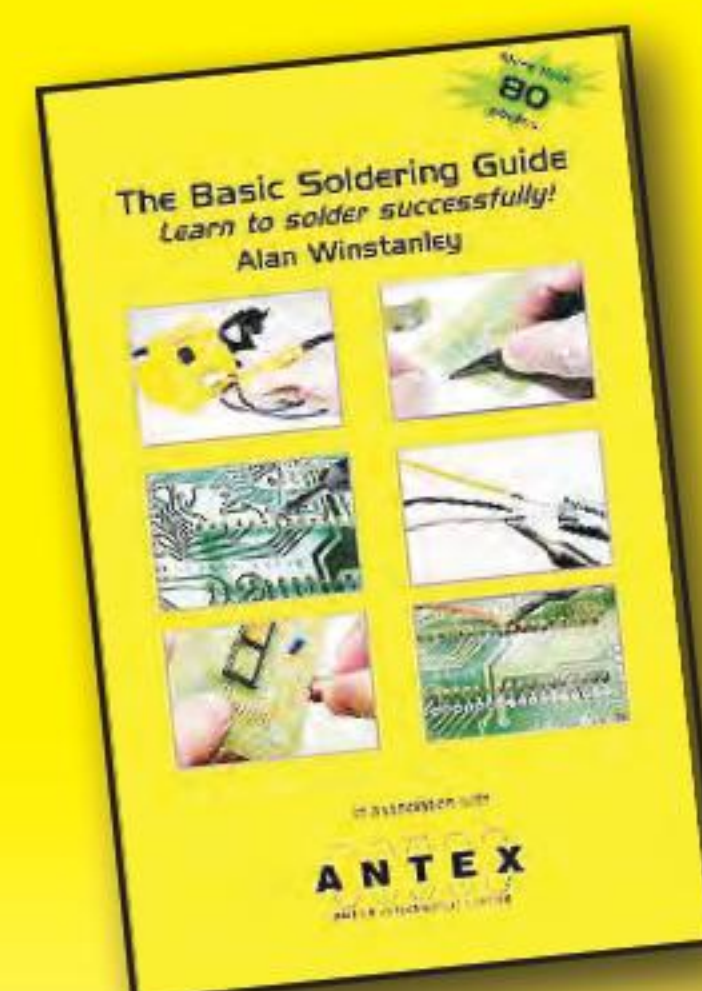
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By Jake Rothman

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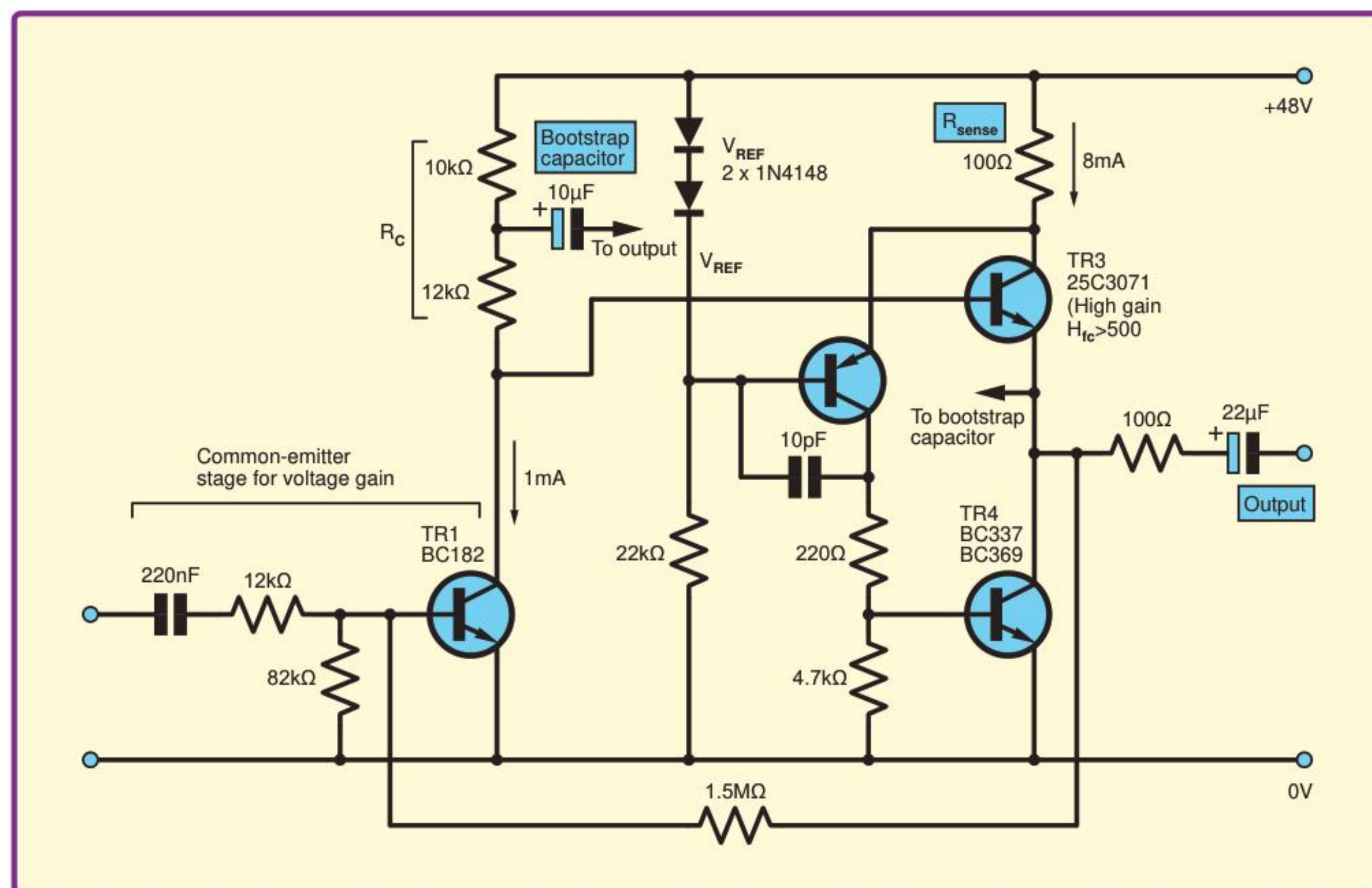


Fig.13. Taylor buffer from April's Audio Out, with added common-emitter amplifier to give inverting gain block. This can be used in the Baxandall volume control if needed.

Discrete design

The discrete version of this circuit is based on a simple common-emitter amplifier combined with the Taylor/ring-of-three buffer (see the *Active volume* article in *EPE*, April 2016) shown in Fig.13. A simplification is

employed using the powerful circuit design trick I call the ‘polarity flip’, where the circuit is turned upside down and the transistors are changed from NPN to PNP and vice versa, as shown in Fig.14. This enables the common-emitter stage to be DC boot-

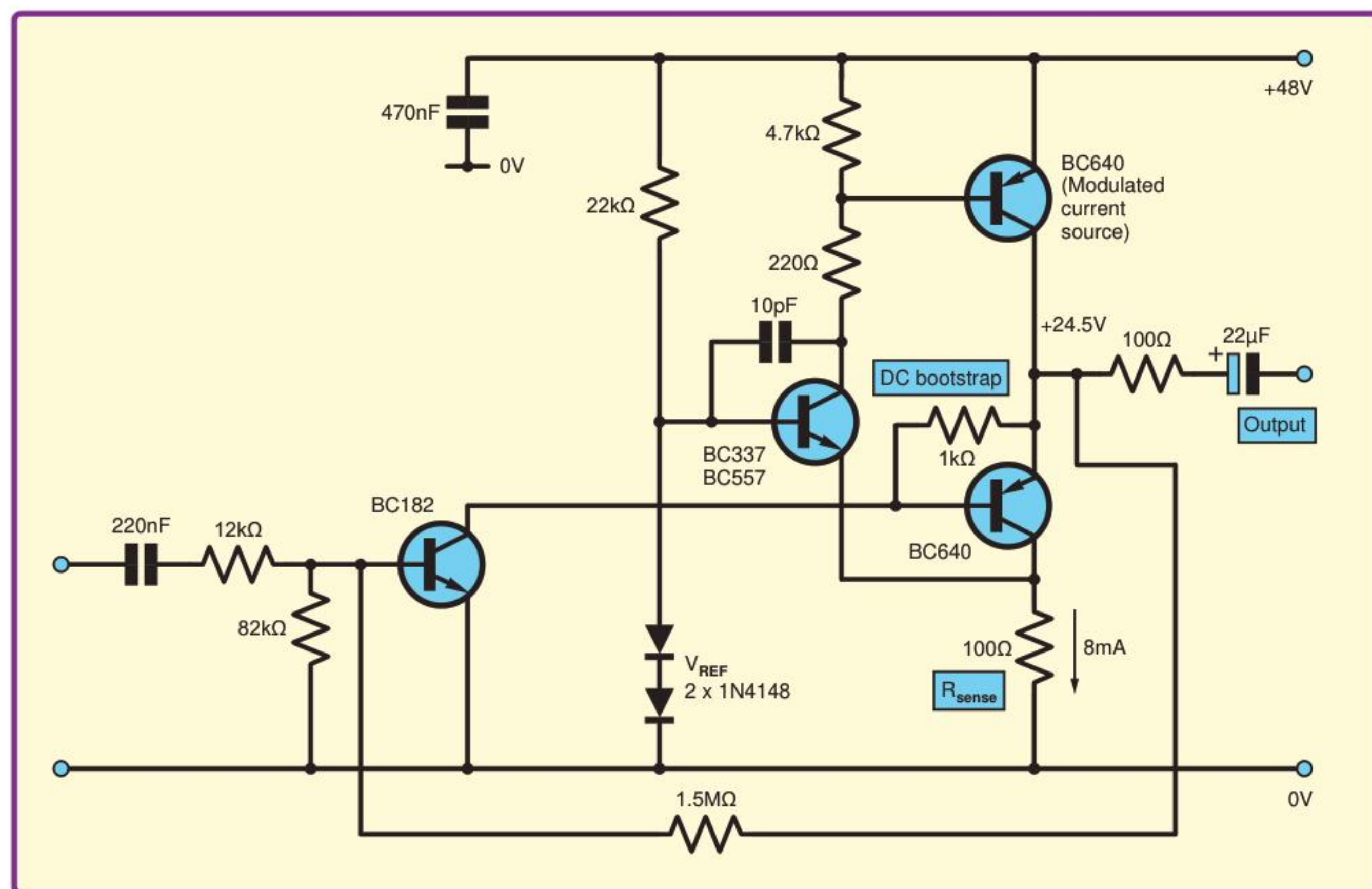


Fig.14. ‘Polarity-flipping’ the circuit in Fig.13. This enables the collector load resistor to be DC bootstrapped and the whole circuit to be powered by the current source, thereby improving hum rejection.

strapped, removing one electrolytic capacitor and one resistor. It also improves the power-supply rejection ratio (PSRR) since the power to the whole circuit is now fed by the current source. Rescaling the low-current circuit to a small power amplifier results in the circuit in Fig.15.

Diode dodges

Note the reference voltage for the common-base transistor TR2 is derived from a reverse-operated Zener diode (D2). This useful technique gives a forward voltage of 0.75V rather than a normal diode's 0.6V. The small voltage difference ensures a full output swing because the transistor remains on throughout the whole cycle. The original circuit used 1.2V, which subtracts 0.6V from the available swing. Another diode (D1) is connected in reverse parallel with the base-emitter junction of TR1. This prevents bias shift when overdriven by ensuring equal positive and negative current paths.

This topology isn't symmetrical like a standard push-pull amplifier, so consequently it has mainly even-order (second) harmonic distortion. However, this is not very noticeable and possibly enhancing to some sources, such 'simple' music (not orchestras). This is minimised by replacing the emitter-follower transistor (TR4/5) with a Sziklai pair (see inset) to equalise the gain on both cycles. The difference is clearly seen in the oscillogram of the amplifier running open loop in Fig.16 where just a single low-gain transistor has been used. This only mattered when driving high currents in a power amplifier. For the original buffer it was not a problem. Using a monolithic Darlington was harder to stabilise, because you can't put a capacitor inside it! I've yet to try a MOSFET.

This little circuit can be built on a bit of Veroboard, as shown in Fig.17 (construction details for this and a PCB version to follow next month). The circuit works in class A up to

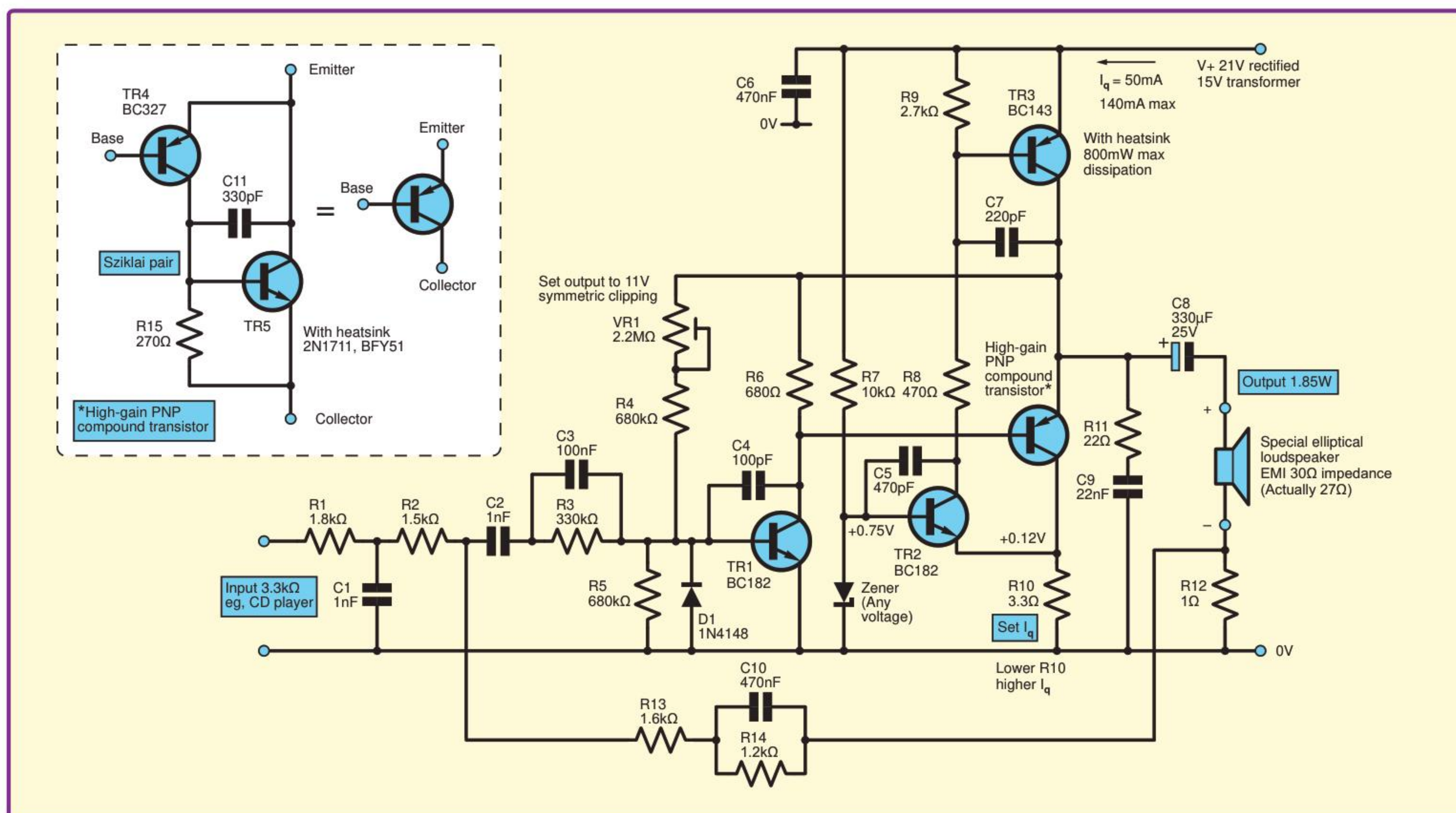


Fig.15. Scaling the circuit in Fig 14 to give higher current to drive the 30Ω EMI speaker, running on 24V rails. The current sensing and equalisation shown in Fig.12 have been added. This circuit's parts cost around £2.00, the valve equivalent about £40.00.

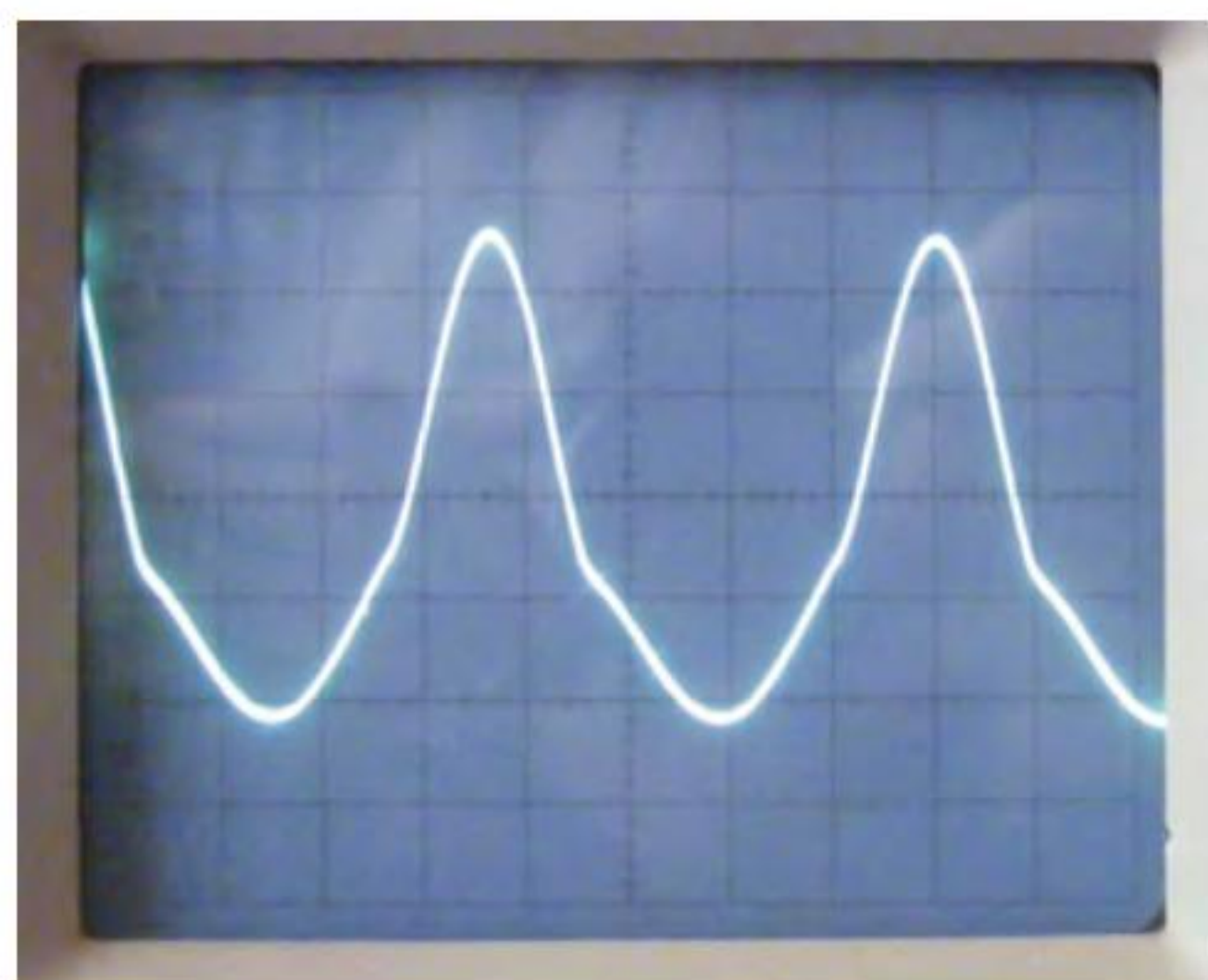


Fig.16. Output of the amplifier in open-loop showing the difference in gain if two identical output transistors are used. Using a compound transistor for the emitter follower equalised both halves of the cycle.

about half a watt, whereupon it moves to a form of class-AB operation. This is indicated by the current drawn, which increases from 60mA quiescent to 140mA at clipping. The distortion residual is low, at around 0.02% until it is driven above 0.5W, where it becomes more spiky, like a class AB amp. At least there is no distortion rise at low levels like many IC-based amplifiers. The current consumption range in this amplifier design is a good compromise, since it is possible to use TO5 output transistors with clip-on heatsinks. For higher power, TO126/220-packaged devices will be needed, which are less convenient to

mount. There is a general sprinkling of small ceramic base-collector capacitors to ensure stability. This is one of the liberties afforded to designers of discrete circuitry. Chip designers have to minimise the use of capacitors because they use a large die area, which is why high-frequency instability and a high minimum gain can be an issue with chips.

Higher power

The 2W amplifier circuit needed an unusual 30Ω speaker (I'm happy to supply them at low cost – just email me at: jacob.rothman@homecall.co.uk). For those needing more power

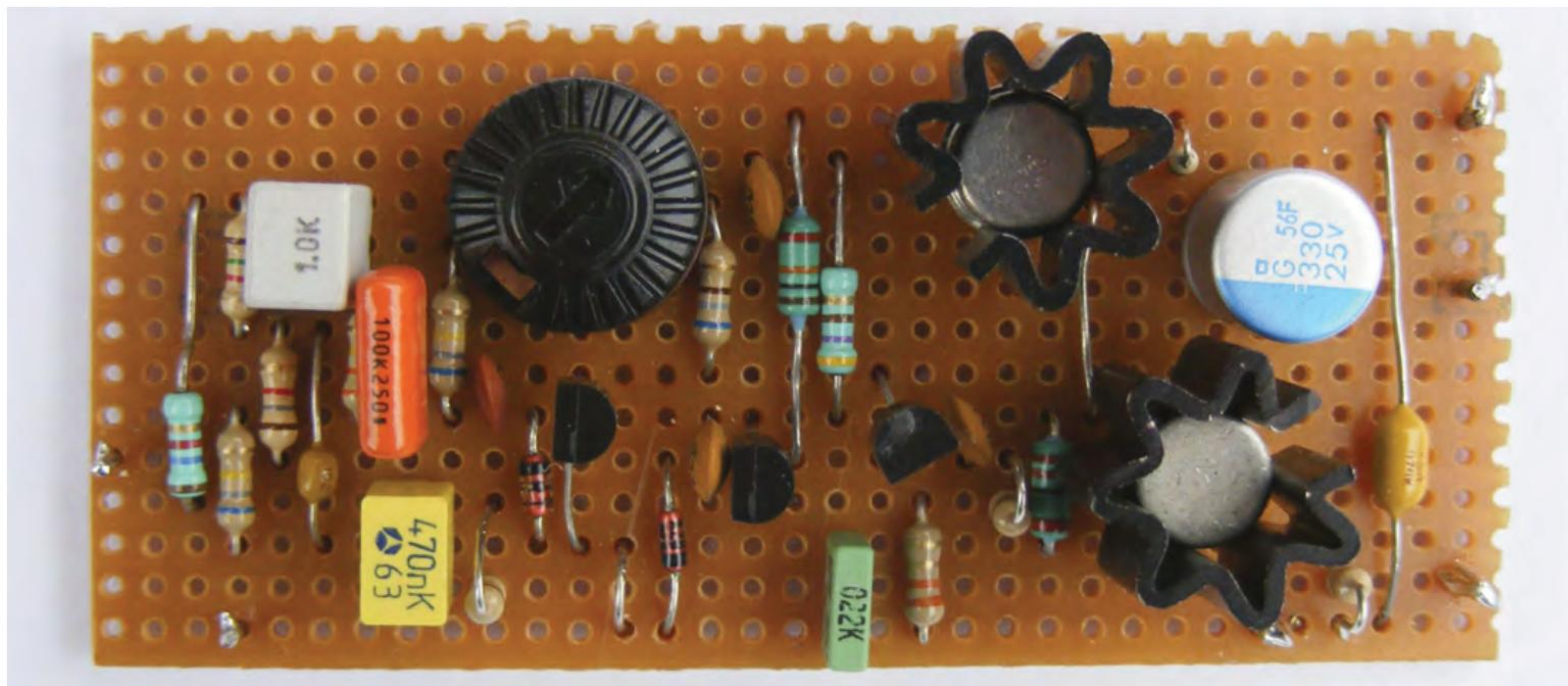


Fig.17. Finished amplifier circuit built on stripboard.

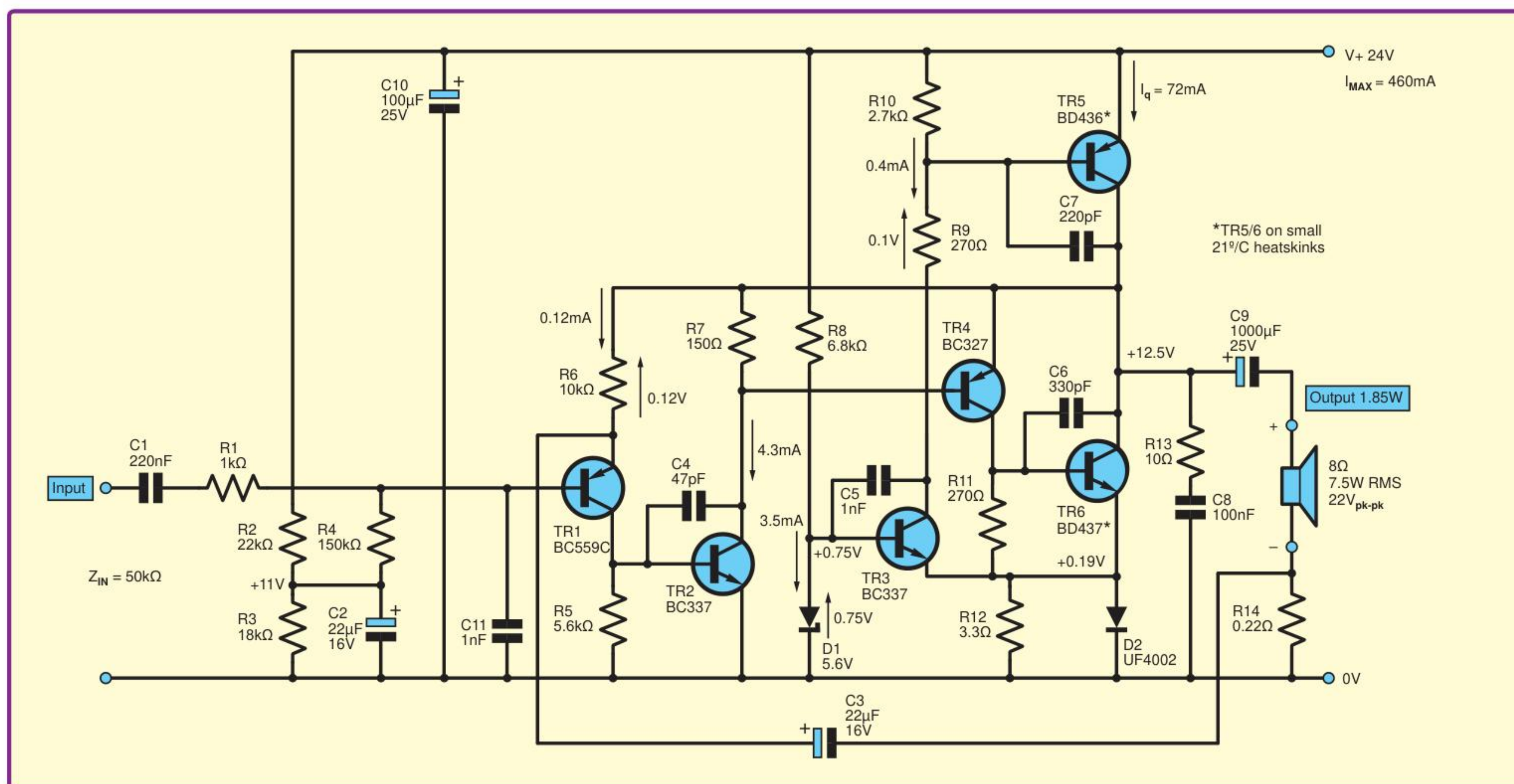


Fig.18. Higher power Taylor amplifier circuit with non-inverting topology

(7.5W RMS) into a normal 8Ω speaker and a higher input impedance, the modified circuit is shown in Fig.18. This has an extra transistor on the input (TR1) to allow a non-inverting configuration to be used. By bypassing the quiescent current (I_q) sense resistor (R12) with a diode (D2) the circuit can be made to operate in class A up until the conduction threshold of the diode is reached, at around 1W, whereupon it begins to operate in class B. An ultra-fast diode such

as a UF4001 has to be used to avoid a switching glitch at high frequencies. Schottky diodes, although very fast, have insufficient voltage drop. The amplifier is shown built on a piece of 2.75×1.75 -inch perf-board in Fig.19. This method of construction is very effective for working out 0.1-inch grid PCB layouts with traditional leaded analogue parts and heatsinks. Fig.20 shows the hardwiring underneath. I guess all this is reinventing the wheel, but I offer this circuit for those who

don't want to use chips, such as the TDA2030 or LM384, and don't want the hassle of the I_q adjustment that bedevils normal discrete class-AB designs. Is that the dulcet tones of the Shipping Forecast I hear?

Next month

My apologies for those of you expecting the promised construction details in this article. However, patience will be rewarded next month when we will finally get to build the amplifier!

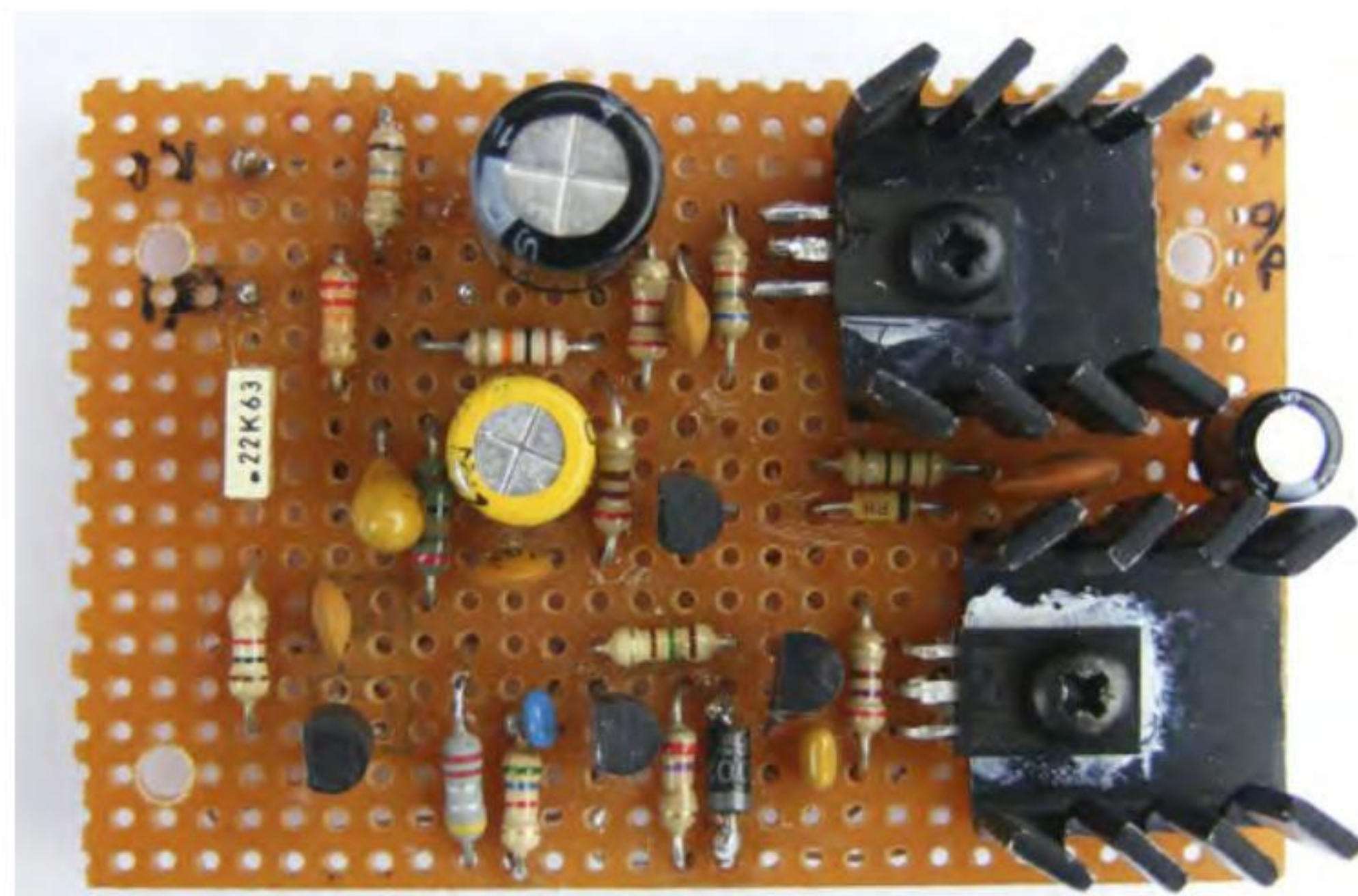


Fig.19. The higher power amplifier built on perfboard. Note the TO126 output transistors and heatsinks required

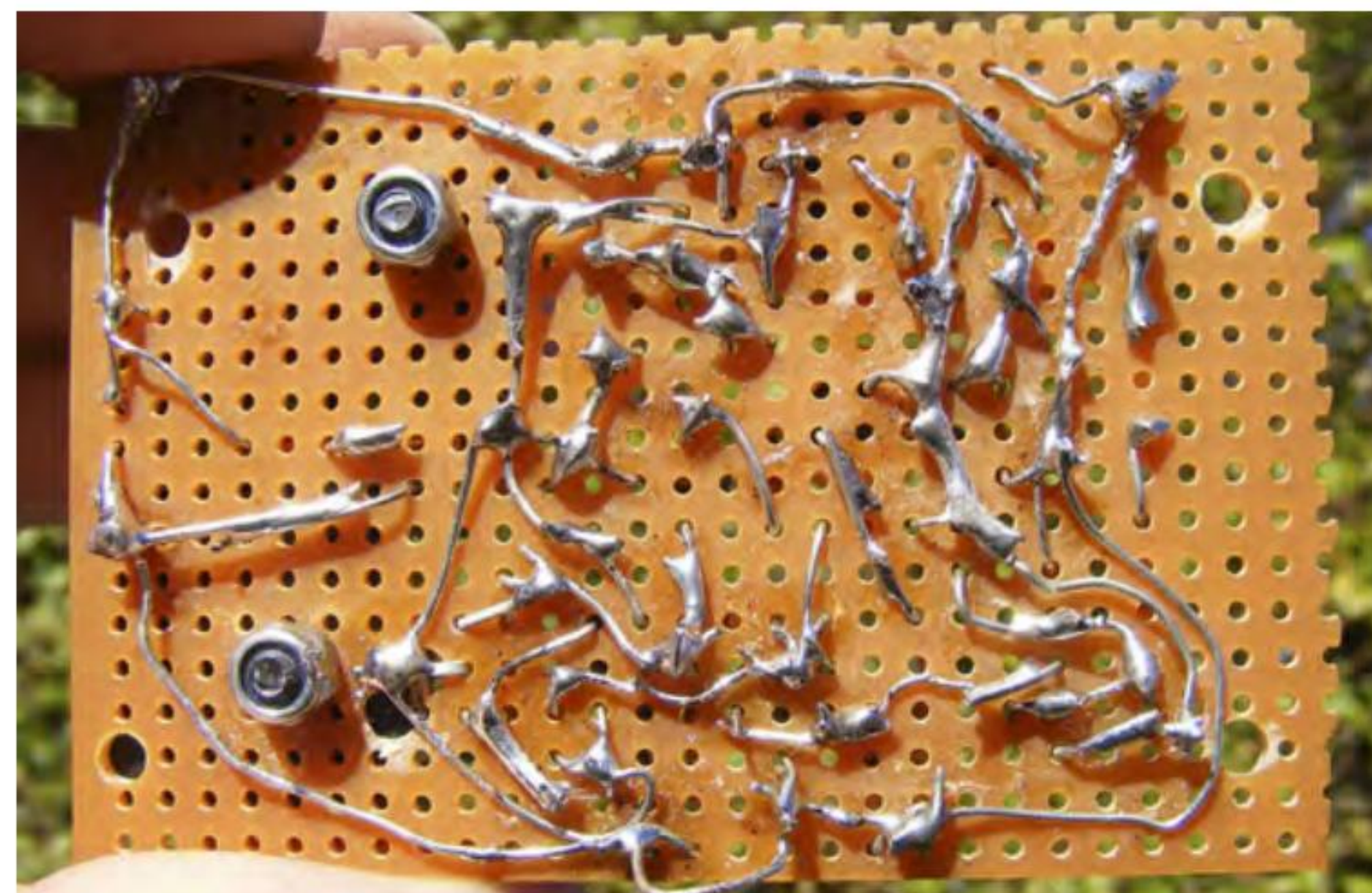
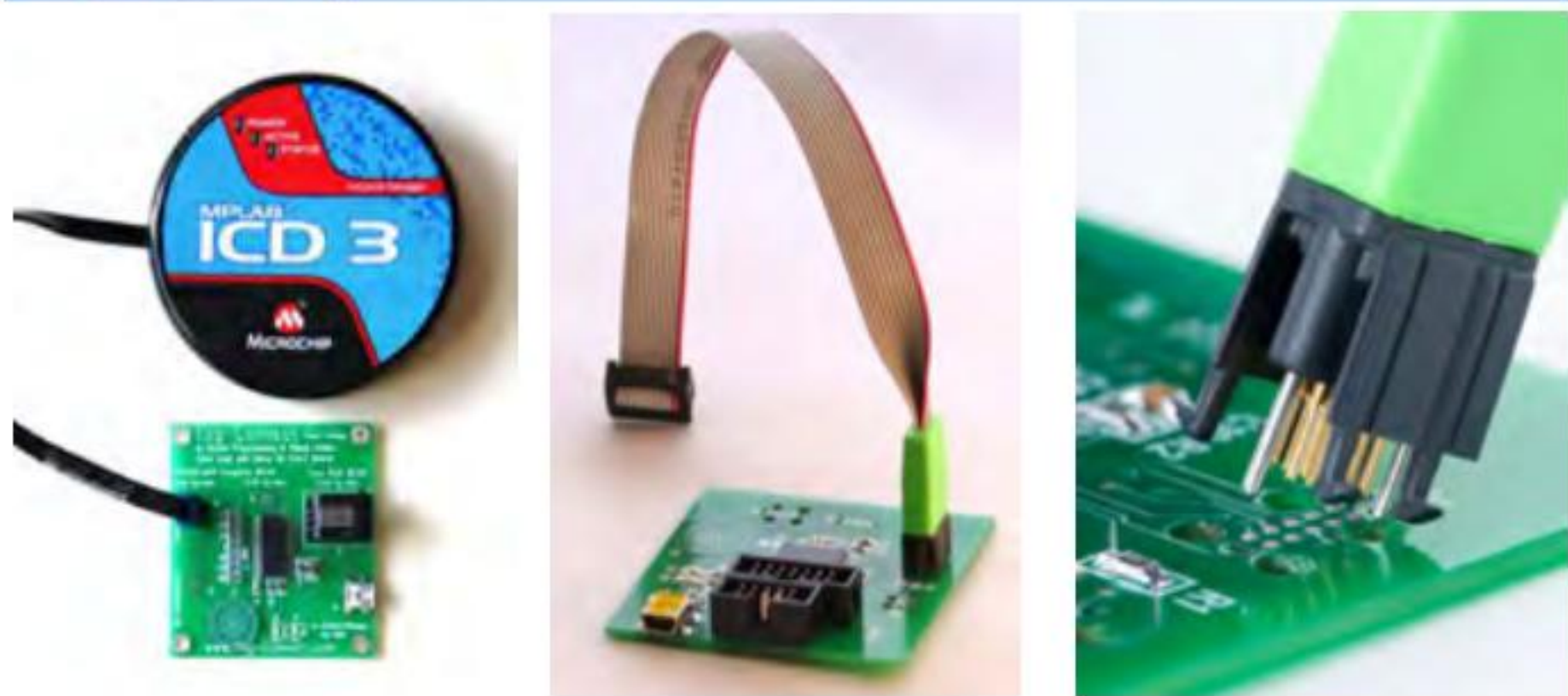


Fig.20. Underside of the perfboard – such constructions are often the start of a PCB design



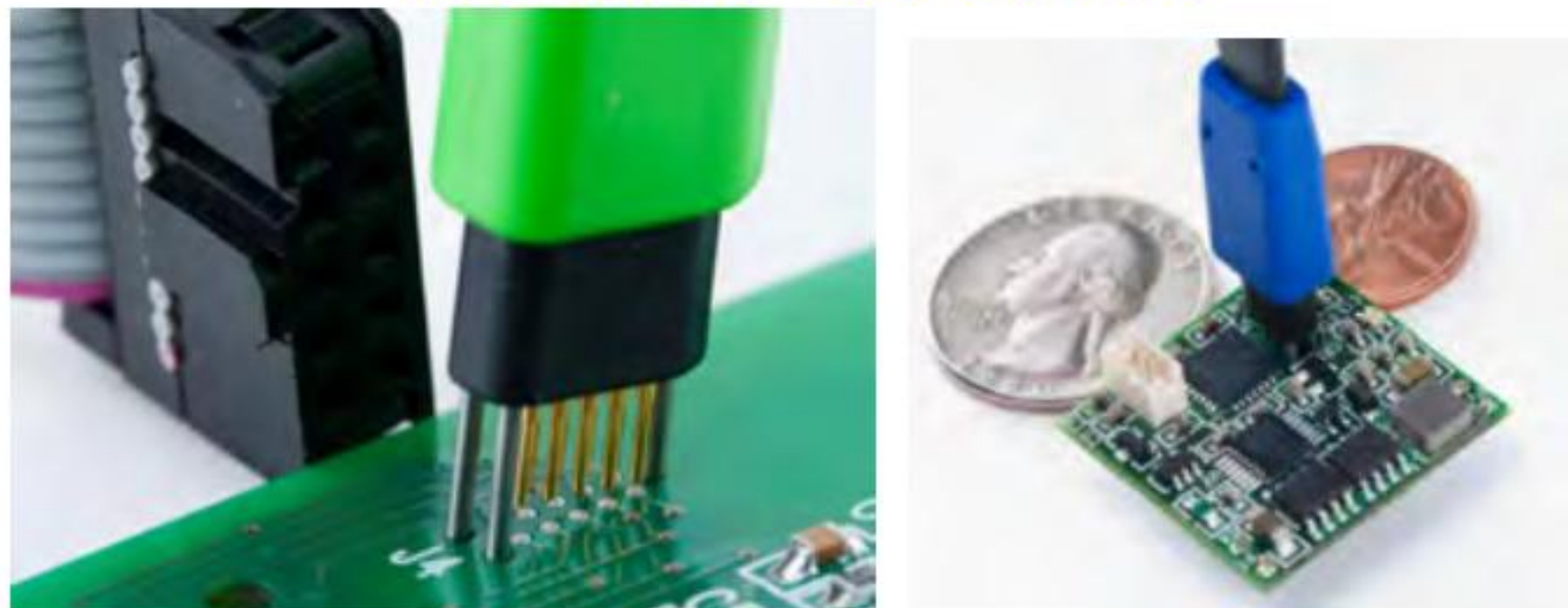
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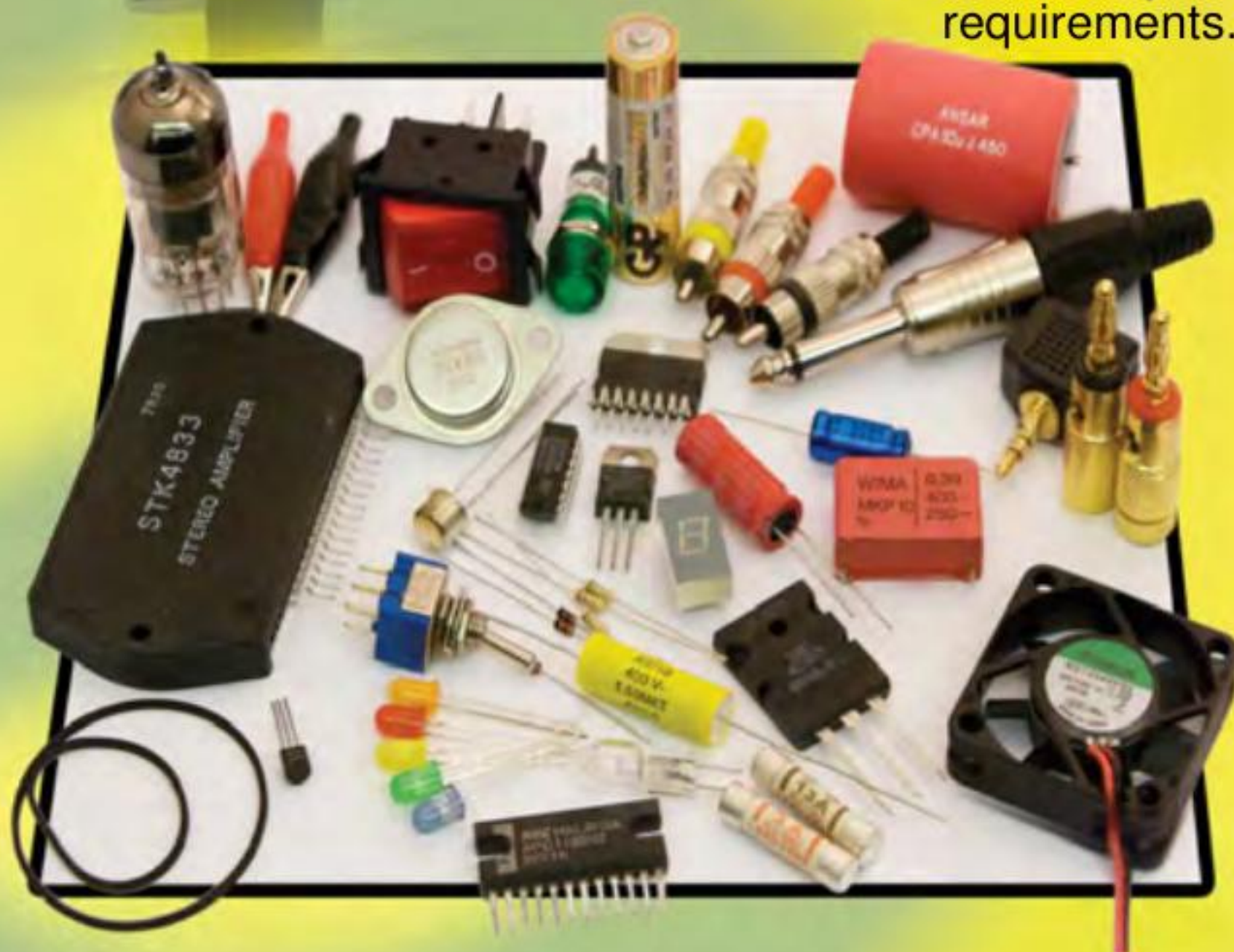
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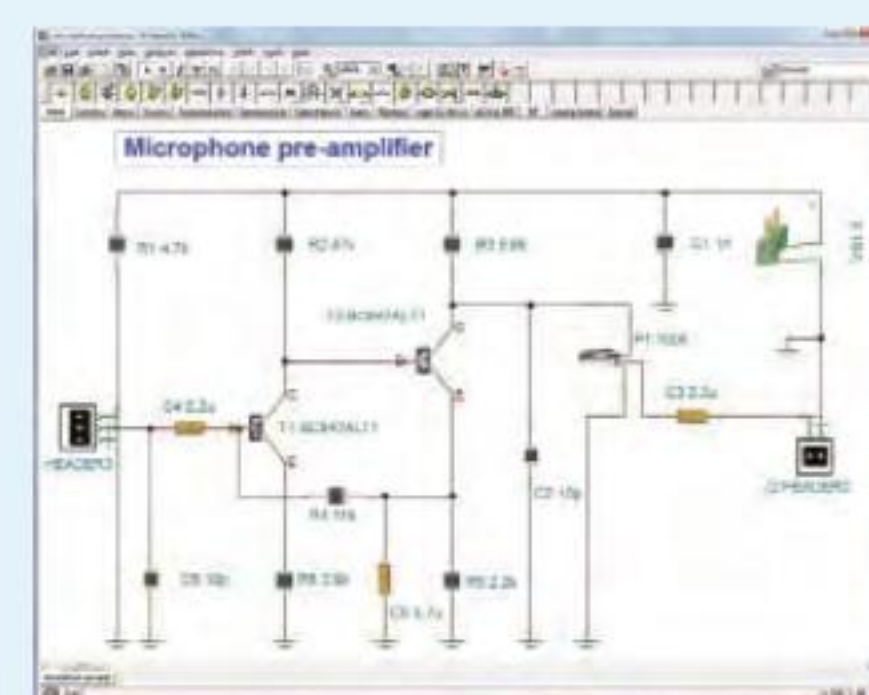
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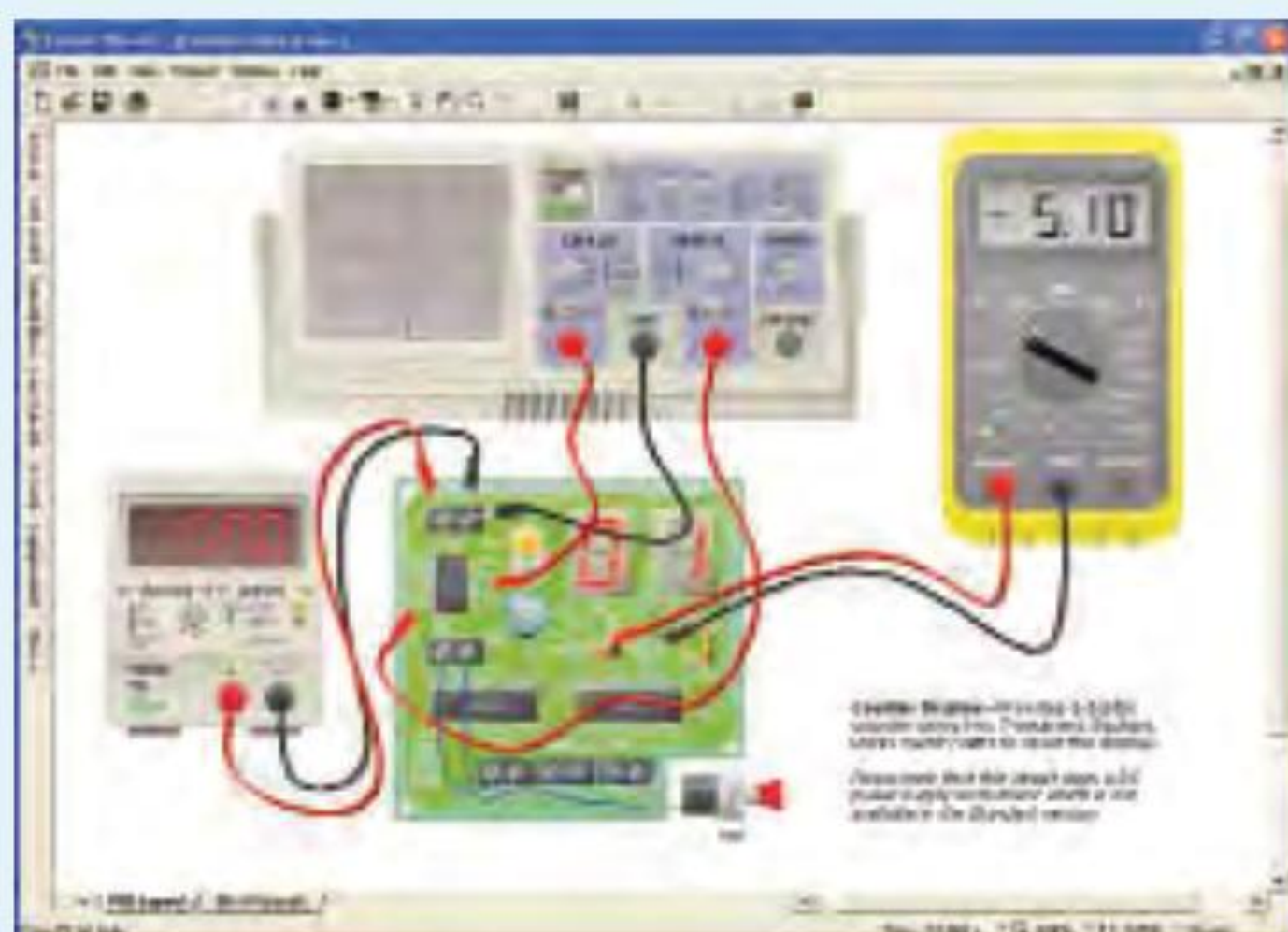
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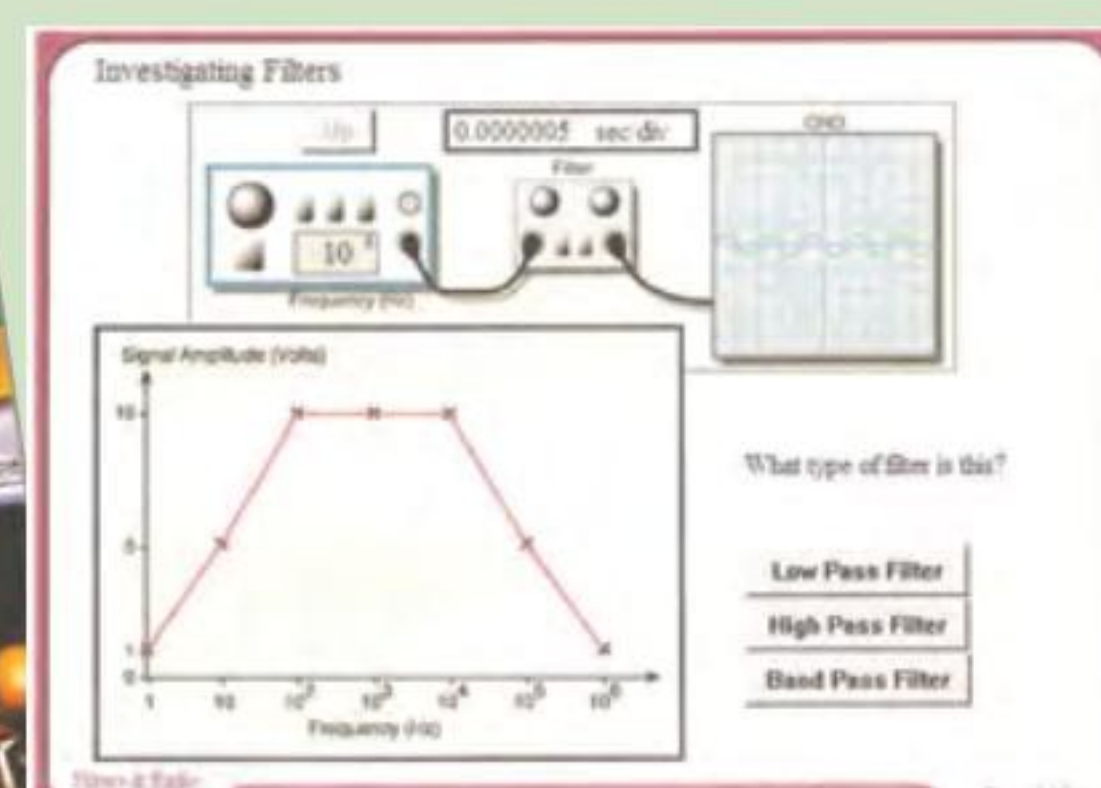
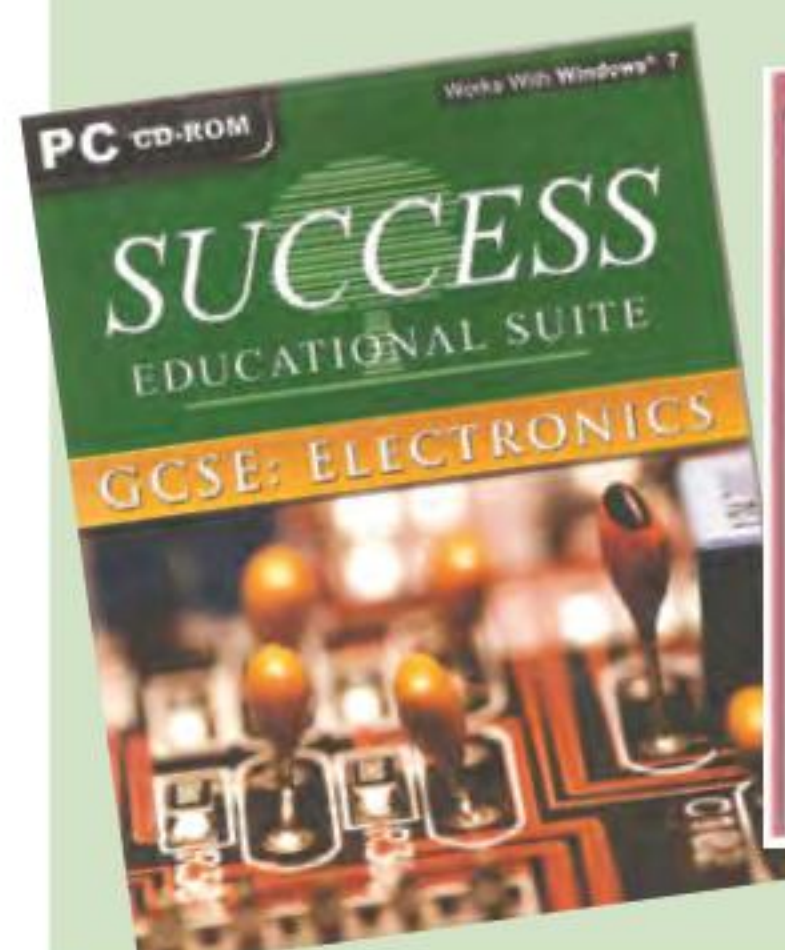
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Max's Cool Beans

By Max The Magnificent

Profligate with power

It's a funny old world when you come to think about it. The first commercial 8-bit microprocessor was the 8008, which Intel priced at US\$120 when it appeared in their catalog in April 1972 (this is close to US\$700 in today's money based on the consumer price index provided by the US Bureau of Labor Statistics). The 8008 boasted approximately 3,500 transistors, had a 14-bit external address bus that could address 16KB of memory, and initial versions could only work with clock frequencies up to 0.5MHz.

How times have changed. In the case of my Caveman Diorama project (see *EPE*, June 2016) there are going to be a number of lighting effects. We have 14 tri-color NeoPixel LEDs at the back of the tunnel, 19 forming the fire, a yet-to-be-determined number in the bottom of the pool, two NeoPixel-based floodlights (these will illuminate the cave painting we're going to have on the wall), and we've also embedded 155 in the cave roof ('just in case'). The thing is that each of these LED groups is going to be controlled by its own 8-bit Arduino Nano microcontroller running at 16MHz. This would seem outrageously profligate to someone from the early 1970s, until they became aware that you can purchase a five-pack of these little beauties for only \$15 from Amazon.

The current state of play for the master control board is illustrated in Fig.1. In the bottom left corner we see a Simblee 29-pin breakout board (we discussed the Simblee in *EPE*, February 2016), which allows me to control everything via Bluetooth using my iPad. In turn, the Simblee controls the six Arduino Nanos on the board, plus a seventh that will be used to control the 'Time Portal', as discussed later in this column.

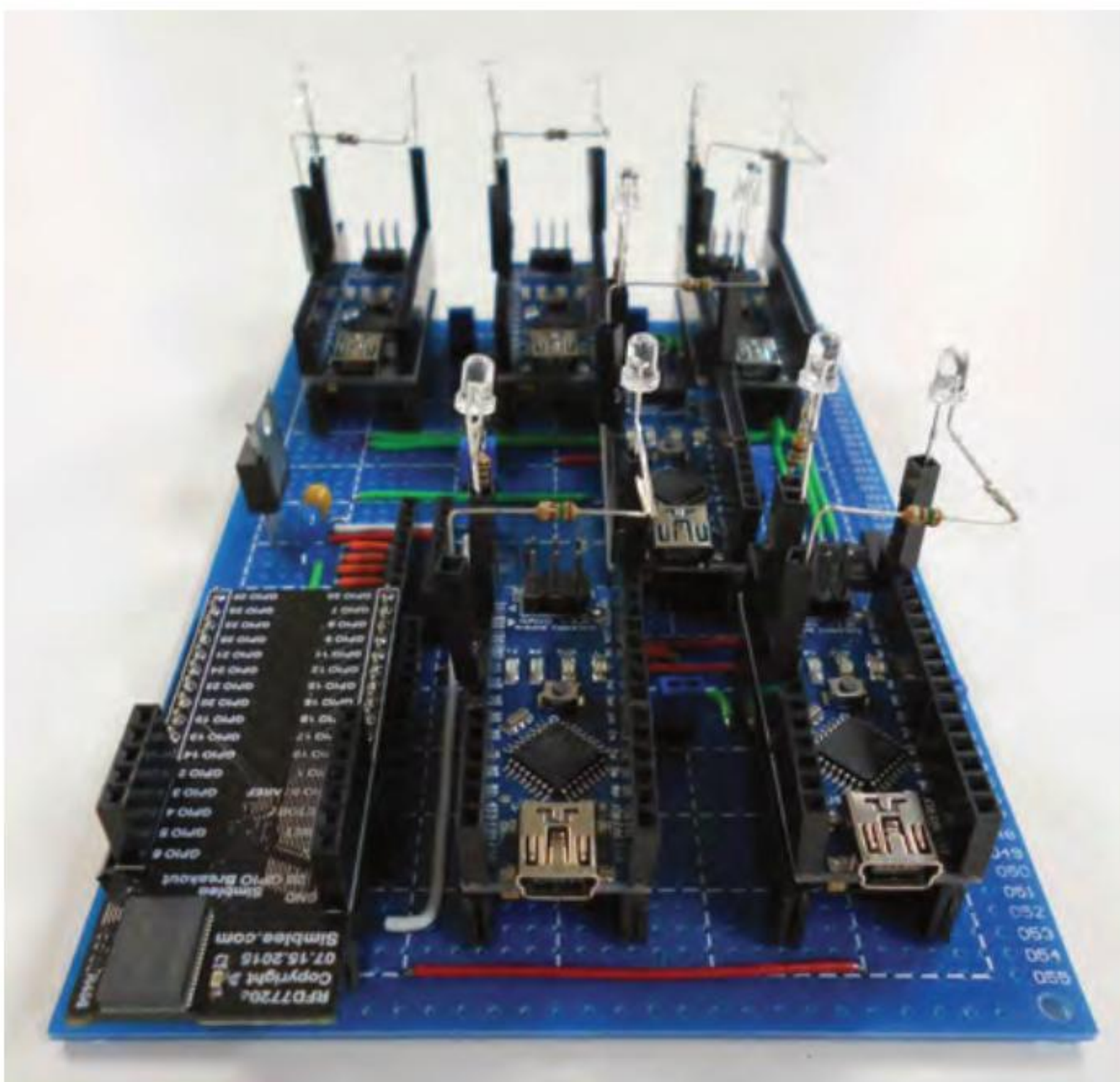


Fig.1. Caveman Diorama master control board

The Nanos are presented in a 'staggered' configuration so as to allow me to easily access their USB-Mini ports for programming purposes. Also, everything is socketed (not doing this has caused me pain before). The two LEDs attached to each Nano are used for testing purposes; they will be removed prior to the final deployment.

The top-level Simblee menu, as seen on my iPad is shown in Fig.2. As we see, the menu system currently accommodates six

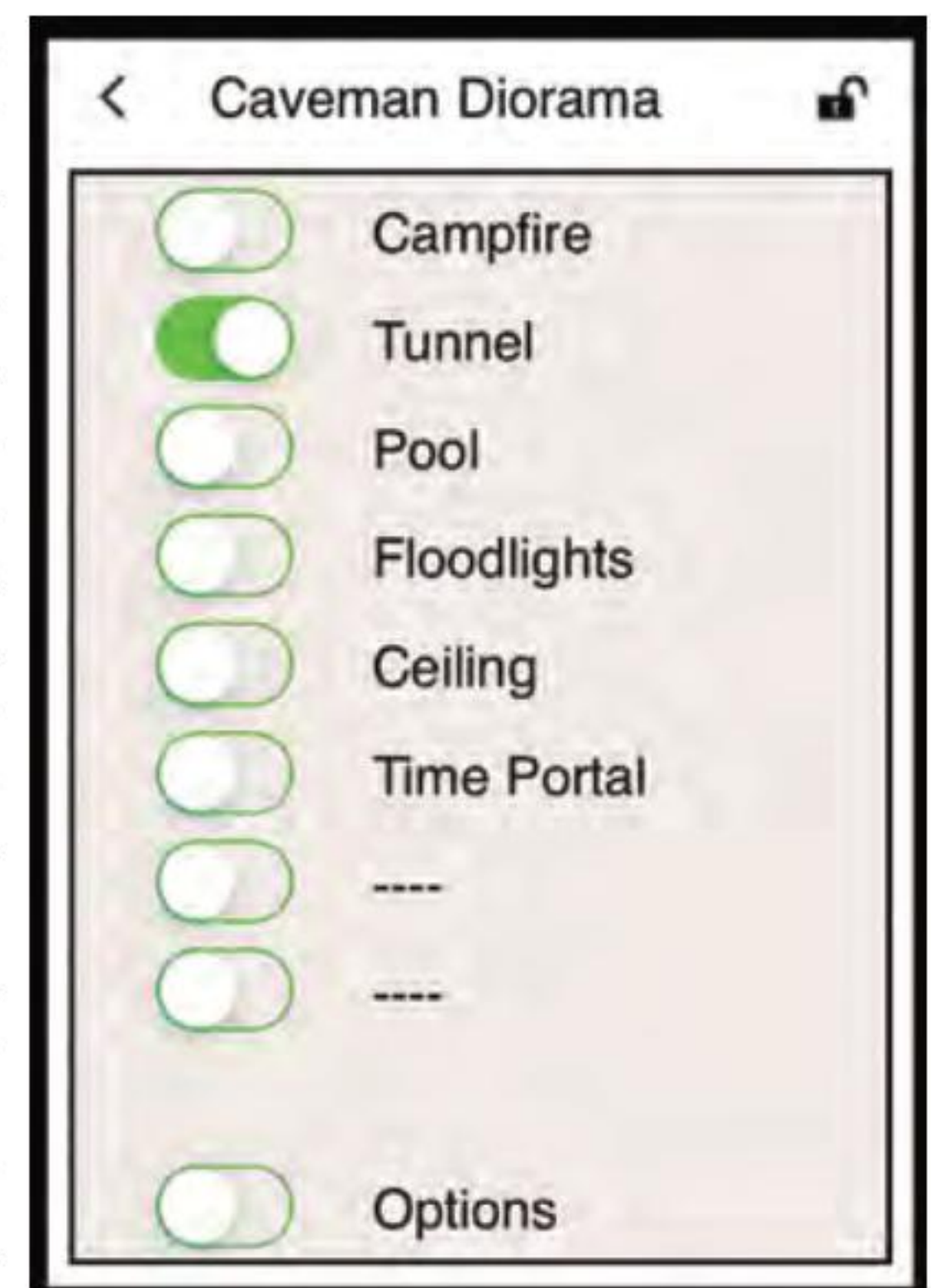


Fig.2. Top level Simblee menu displayed on an iPad.

defined effects with room for two more. Clicking the 'Option' switch will take you to the options associated with the currently selected effect (you can see the current state of this menu code here: <http://bit.ly/1szS7nd>).

The way I've set this up, each of the Nanos on the controller board is controlled by three of the Simblee's pins, which means we can have eight options for each effect (or seven if we assume that the first option is for that effect to be turned off). The way I set this up was to create a common skeleton program that can be used as the base for each of the Nanos. I'm currently working on the Tunnel code and, at this time, I've created three effects: a low red glow, a breathing effect based on a sine function, and a pretty effective arc welder effect (you can see the current state of this Tunnel code here: <http://bit.ly/1WTfu8F>). But that's not what I wanted to talk to you about...

Is that the time?

As I've mentioned in previous columns, one of the elements we're going to have in the cave will be a Time Portal, which will explain my presence in the scene, along with any other anachronisms, such as the floodlights illuminating the cave paintings.

As an aside, we were originally thinking of having power cables from the floodlights (and other items like a boom box) snaking back to a plug panel mounted on the frame of the Time Portal, but then we decided this would look silly. Our latest plan is to have these items connected to a number of truck batteries. In turn, these batteries will be connected to a generator attached to a bicycle being peddled by a very hot and sweaty caveman, but I digress...

As usual, we started out by creating card/paper mock-ups. Since we are working at 1/32 scale, a 6-foot man will be 2¼-inches tall in the diorama, so we decided

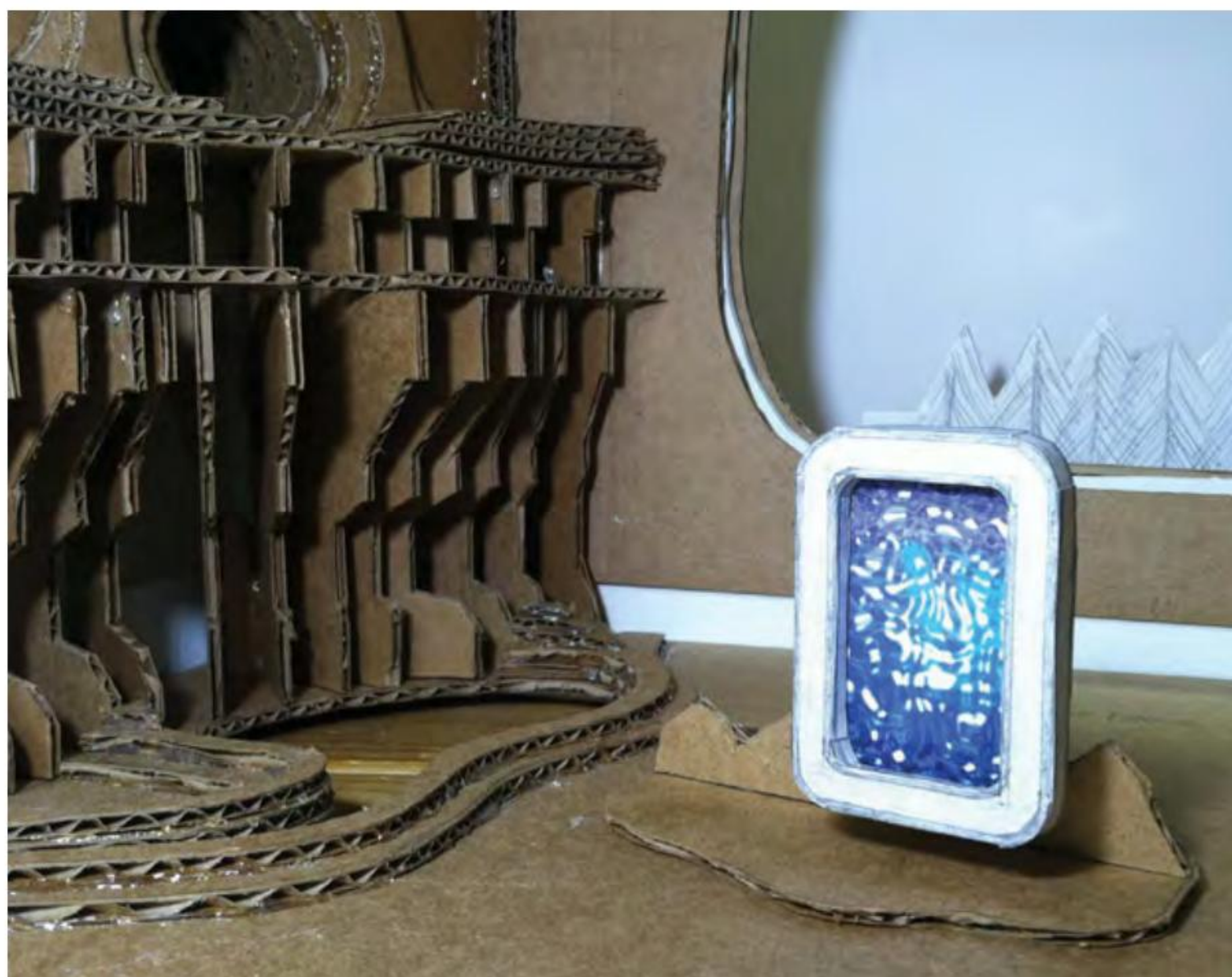


Fig.3. An early conception of the time Portal

that the height of the Time Portal should be around 2½-inches. The portal itself will be a small LCD screen surrounded by a 3D printed ‘stone’ doorframe. Initially, we considered two versions – a free-standing doorframe mounted on the floor versus a portal ‘floating’ in the air (this latter option is illustrated in Fig.3).

As it turned out, this decision was eventually taken away from us. After searching far and wide, we opted to use a 2.8-inch diagonal TFT LCD from Adafruit (<http://bit.ly/1N1Ha1R>). This little rascal comes with a breakout board that also carries the necessary controller chip along with a Micro-SD cardholder. The idea is to have the display alternating between a default ‘time portal rippling mirror’ type image and a large random selection of other ‘interesting’ images, all of which will be stored on a Micro-SD card attached to the back of the display.

In Fig.4 you can see one such image – a man sitting on a chair looking out at a post-apocalyptic landscape. Observe the black band around the edge of the image. In particular, observe that this black area is really large at the bottom of the display. On the bright side, the 2.8-inch quoted by Adafruit really does refer to the actual image area. The problem is that, if we make the doorframe wide enough to cover the black area at the bottom of the display – along with the breakout connections below – then the frame will be totally out of scale to the rest of the display. The solution is to return to having a floor-mounted time portal, but to actually present it standing on a small platform faced by a couple of flagstone steps, thereby covering the unwanted areas of the display.

I’m currently having a lot of fun rooting out all sorts of interesting images. I started out with alien landscapes, post-apocalyptic scenes, jungles, beaches, pyramids, and weird, wonderful, and beautiful visions of the past, present, and future (I don’t like to limit myself unduly). Furthermore, I subsequently decided that it would be nice to ‘give a nod’ to classic science fiction films (eg, *Forbidden Planet*, *The Day the Earth Stood Still*, *2001: A Space Odyssey*, *Planet of the Apes*...) and television programs (*Lost in Space*, *Land of the Giants*, *Quantum Leap*, *The Twilight Zone*...).

Not quite so straightforward

There is, however, a small fly in the soup. As you can see in this video (<http://bit.ly/1TyScnl>), it currently

takes around four seconds to ‘wipe’ each new image over the existing one (the video shows the display being driven by an Arduino Uno, but this will be replaced by a Nano in the final deployment).

There are several aspects to this delay. First of all, we are using the Arduino libraries supplied by Adafruit. These require us to use 24-bit BMP images (8 bits each for the red, blue, and green elements of each pixel). Next, we are using the SPI interface to read the images from the Micro-SD card on the back of the display’s breakout board and also to write the images back to the display itself.

Before you ask, the display isn’t double-buffered (we already thought of that). Two solutions that do present themselves are: a) reduce the images to 16-bit BMPs, thereby reducing the amount of data being read from the card and written to the display by 33%, and b) continue to read the images from the Micro-SD card using the SPI interface, but to then write them back to the display using the significantly faster 8-bit parallel interface.

There are also a variety of transition effects we can play with. Of course, we also have a bunch of limitations to battle our way around, such as the fact that each 24-bit 240x320 pixel image occupies ~0.25MB on the Micro-SD card, while the Arduino Nano has only 2KB of on-chip SRAM, but overcoming these obstacles is what makes this stuff so much fun.

What makes it even more fun is that I’m not the one doing the work; my chum Daniel Whiteley has a degree in Electrical Engineering, he works on FPGAs for a living, and – in his spare time – he dabbles with projects like driving LCD displays with small microcontrollers. Daniel is currently spending his weekends working furiously on the Time Portal and I expect to have great things to report in a future column. Until then, have a good one!



Fig.4. The display showing a test image.

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ADVERTISERS INDEX

BETA LAYOUT	72
CRICKLEWOOD ELECTRONICS	63
ESR ELECTRONIC COMPONENTS	6
HAMMOND ELECTRONICS Ltd	19
iCSAT	28
JPG ELECTRONICS	72
LABCENTER	Cover (iv)
LASER BUSINESS SYSTEMS	67
LedLabs	67
MICROCHIP	Cover (ii), Cover (iii) & 10
PEAK ELECTRONIC DESIGN	37
PICO TECHNOLOGY	63

POLABS D.O.O.	36
QUASAR ELECTRONICS	2/3
STEWART OF READING	67
TAG-CONNECT	63

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Next Month

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LED Party Strobe

Here's a fun, simple and cheap project – turn a standard 230VAC 30W LED floodlight into a powerful party strobe light.

Teach-In 2016 – Part 8

Next month, *Teach-In 2016 Arduino World* will look at a simple IR remote control based on the Arduino Uno and Nano. *Arduino Workshop* will introduce you to infra-red transmitters and receivers, while our programming feature, *Coding Quickstart* will introduces the infra-red remote library. Our *Get Real* project will describe the design and construction of an Arduino multichannel infra-red remote controller that will allow you to control effortlessly a host of domestic gadgets.

PLUS!

All your favourite regular columns from *Audio Out* and *Circuit Surgery* to *Electronic Building Blocks*, *PIC n' Mix* and *Net Work*.

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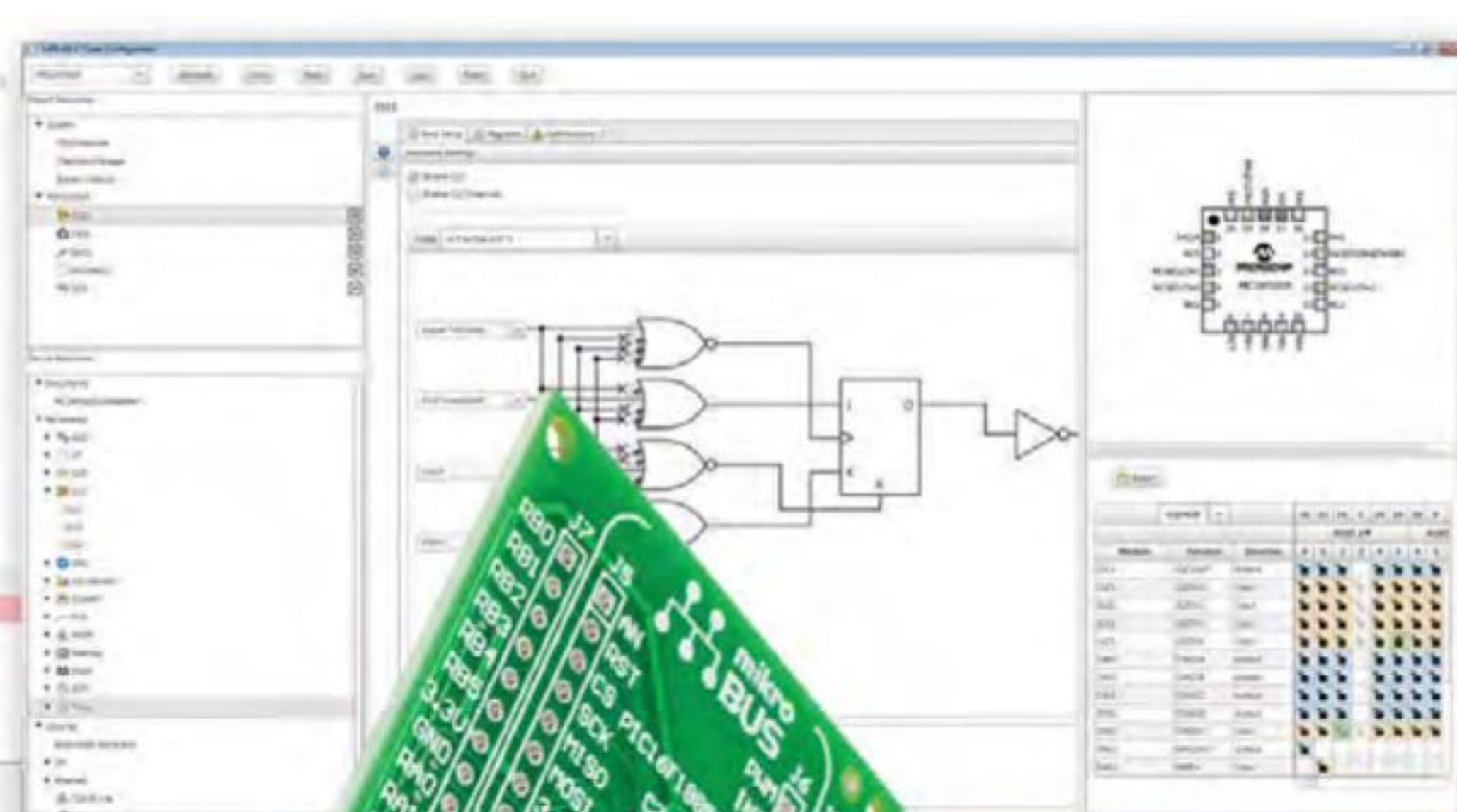
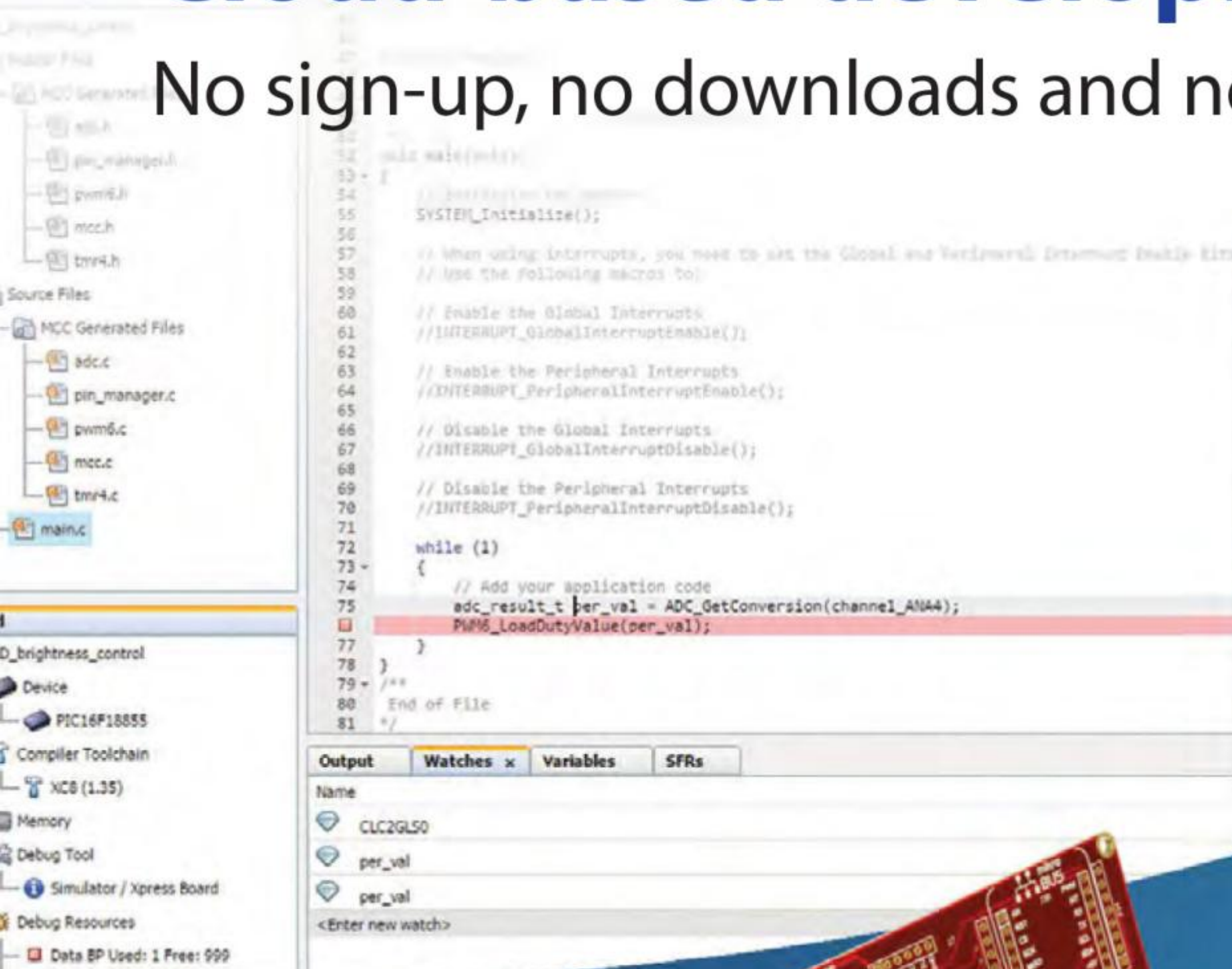
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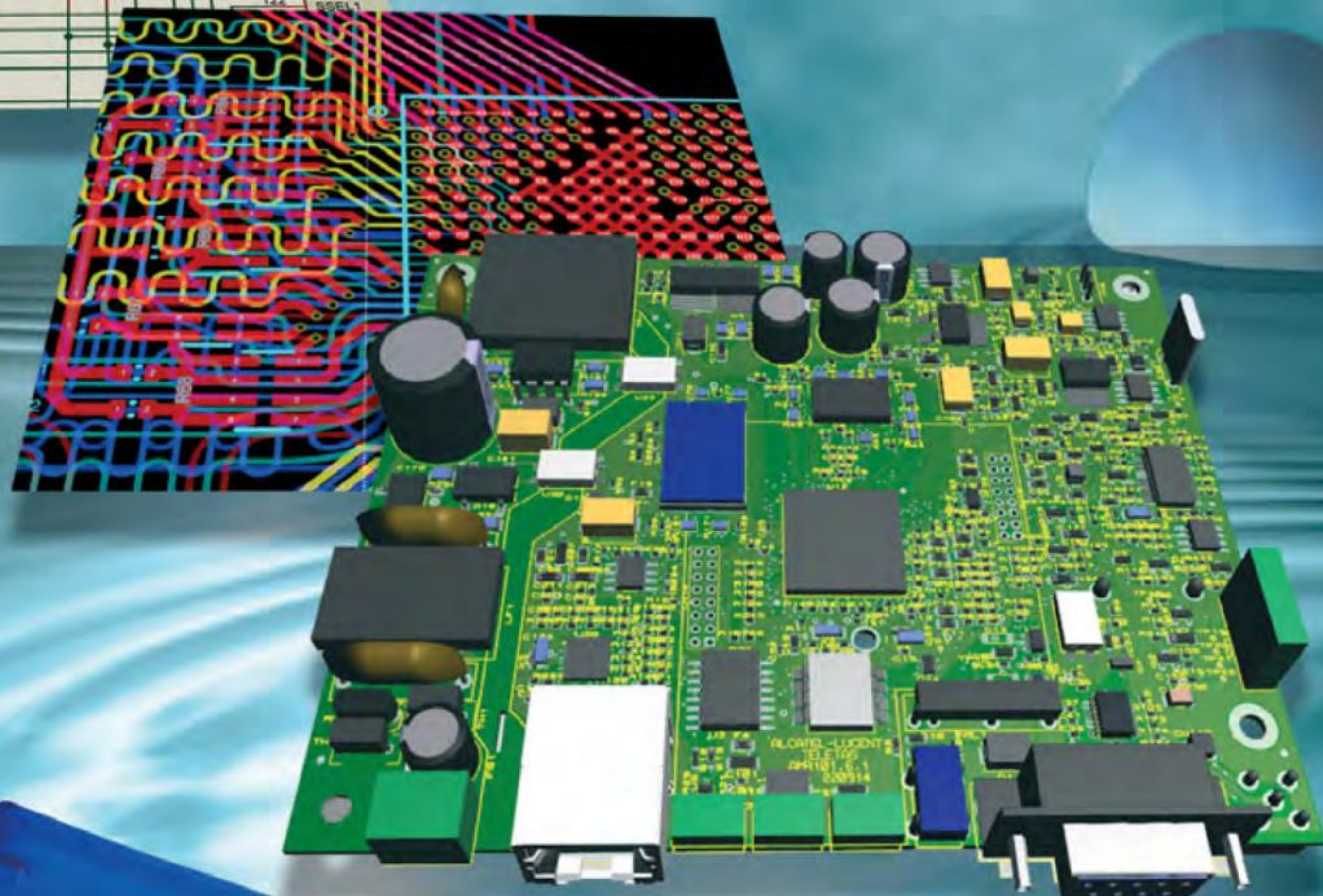
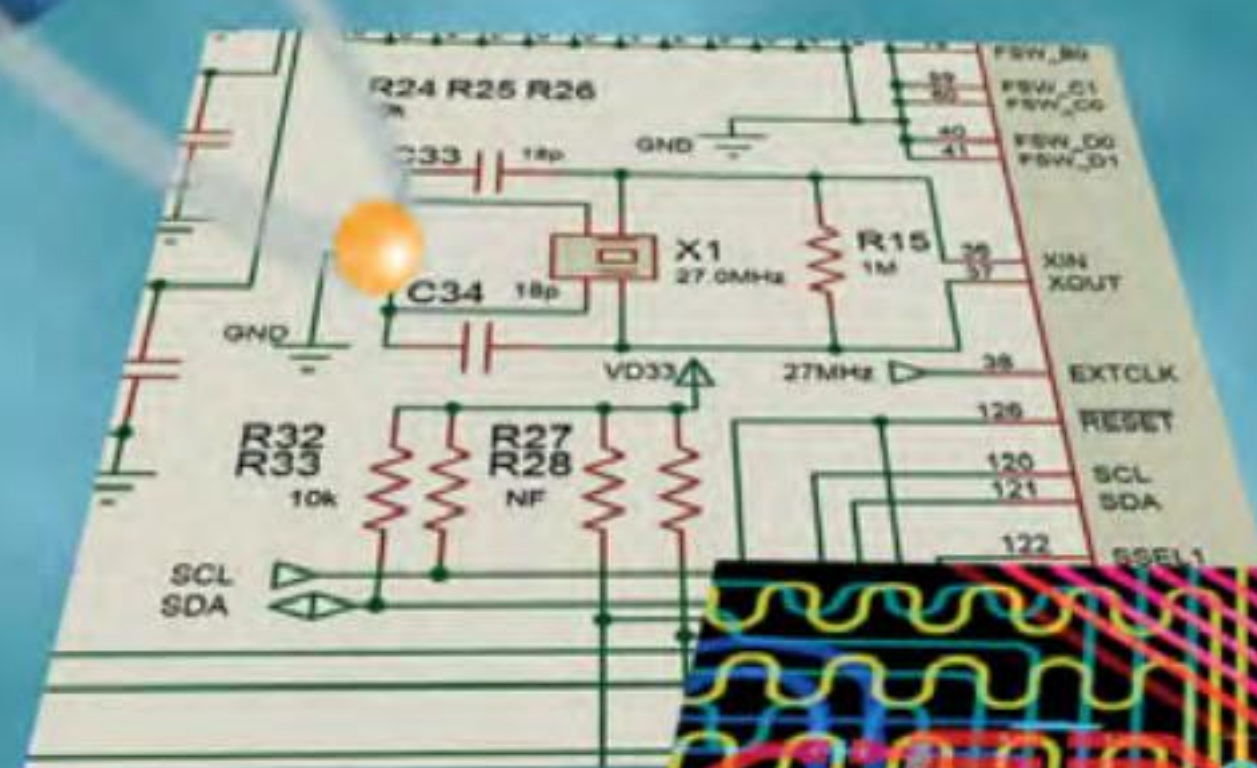
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